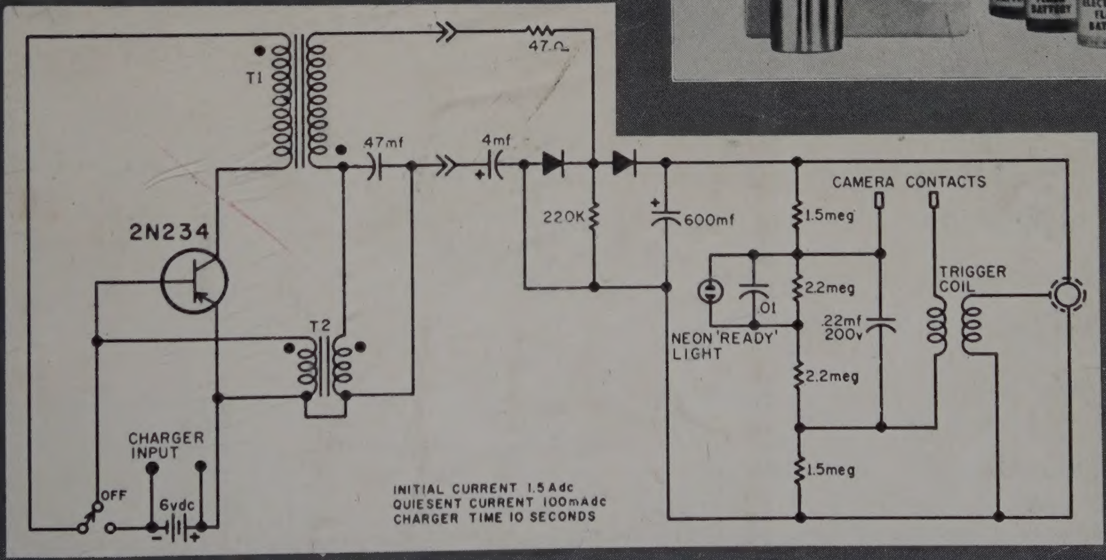
February 1959

75¢

SEMICONDUCTOR PRODUCTS

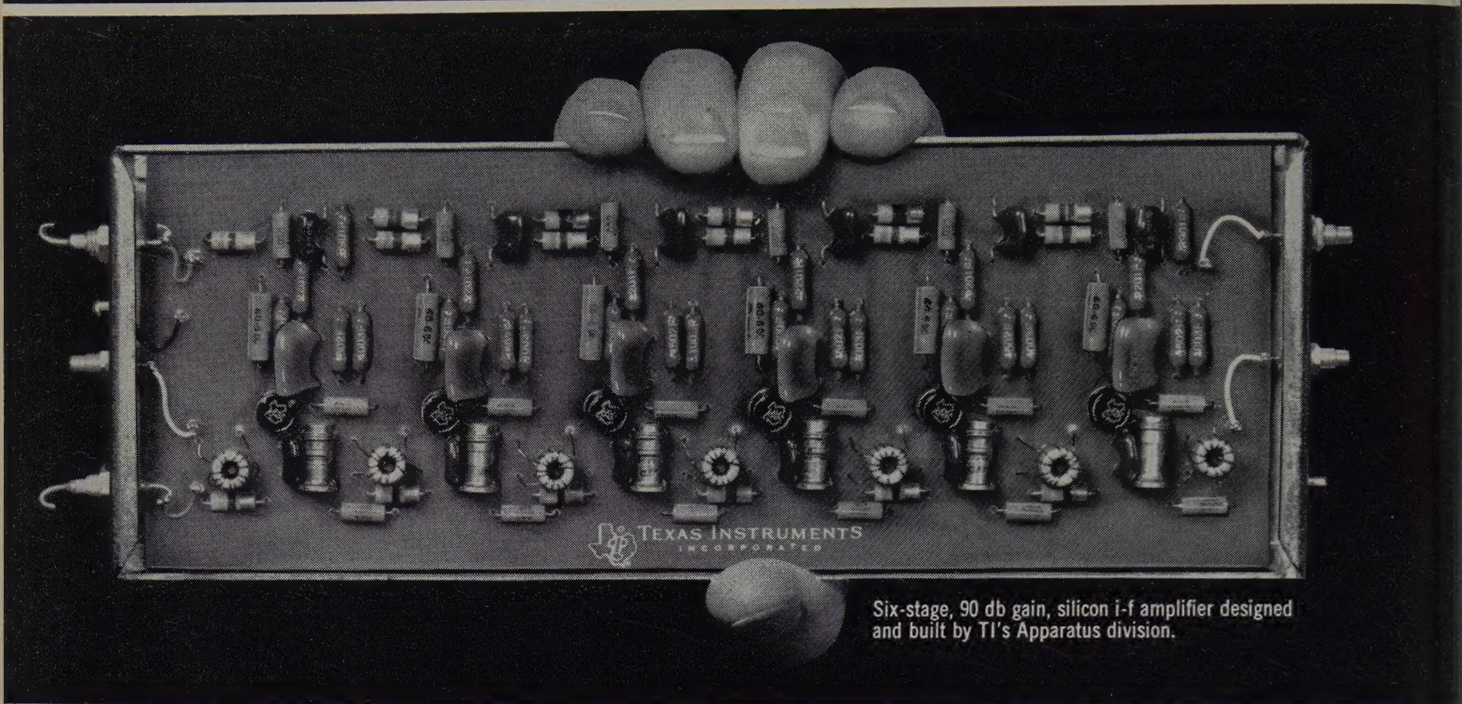
Electronic Flash Using Transistors



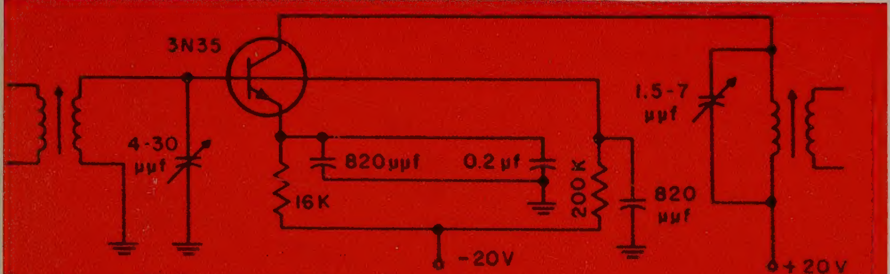
Transistor Noise Factor Tester

Intermetallic Semiconductor Compounds

105 db gain in 60 mc I-F strip



Six-stage, 90 db gain, silicon i-f amplifier designed and built by TI's Apparatus division.

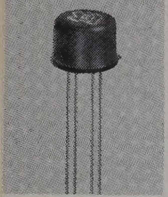


One stage of 105 db gain, eight stage, 60-mc i-f strip.

Write on your company letterhead for 105 db gain, eight stage, 60-mc i-f amplifier applications brochure.

...with TI 3N35 silicon transistors

Actual Size



105 db I-F STRIP CHARACTERISTICS

Bandwidth: 20 mc at 3-db down

Center Frequency: 60 mc

No neutralization required

The high gain of TI 3N35 transistors at high frequencies permits mismatch in the interstage coupling networks to eliminate complicated neutralizing circuitry. You save extra component costs, design with ease and gain added reliability . . . because the mismatch in this application sacrifices only 2.55 db gain per stage!

Designed for your high frequency oscillators, i-f, r-f, and video amplifier circuits, the TI 3N35 features . . . 20-db power gain at 70 mc . . . typical 150-mc alpha cutoff . . . operation to 150°C. These characteristics make transistorization feasible for radar, communications, missile, and other high reliability military applications.

In commercial production at TI for two years, the 3N35 has a product-proved record of high performance and high reliability. These units are *in stock now!* For *immediate delivery*, contact your nearby TI distributor for 1-249 quantities at factory prices . . . or call on your nearest TI sales office for production quantities.

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for semiconductor applications

Merck Doped Single Crystal Silicon—offers doped single crystals of high quality. Yields of usable material are reported to be especially high when device diffusion techniques are used. Merck doped crystals are now available either in n or p types. Either type of crystal can be furnished in resistivities of 20 to 50 ohm cm., 50 to 100 ohm cm., 100-300 ohm cm. and higher. Minimum lifetime for Merck doped crystals—100 microseconds.

Merck Single Crystal Silicon—offers manufacturers without floating-zone equipment semiconductor silicon of a quality unobtainable elsewhere. No crucible-drawn crystals can match the reliability of Merck single crystal material in semiconductor devices. Merck Single Crystal Silicon is available with min. resistivity of 1000 ohm cm. p type.

Merck Polycrystalline Billets—have not been previously melted in quartz, so that no contamination from this source is possible. Merck guarantees that single crystals drawn from these billets will yield minimum resistivities over 50 ohm cm. for n type material, and over 100 ohm cm. for p type material. Merck Silicon Billets give clean melts with no dross or oxides.

Merck Polycrystalline Rods—are ready for zone melting as received . . . are ideal for users with floating-zone melting equipment. Merck Polycrystalline Rods (8½ to 10½ inches long and 18 to 20 mm. diameter—smaller diameters on special order) yield more usable material. In float-zone refining one can obtain minimum resistivities of 100 ohm cm. p type with minimum lifetime of 200 microseconds.

For additional information on specific applications and processes, write Merck & Co., Inc., Electronic Chemicals Division, Dept. ES-1.

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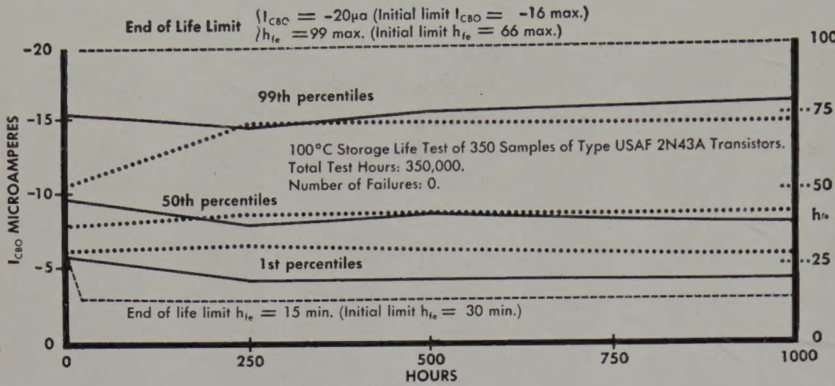
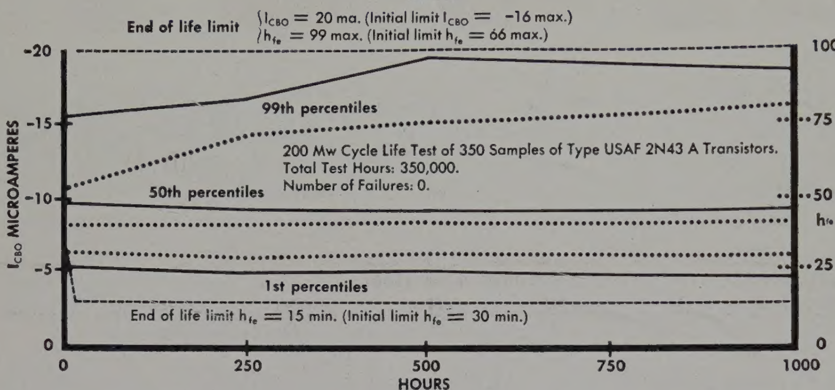
SILICON —a product of MERCK

BASE BORON CONTENT BELOW ONE ATOM OF BORON PER SIX BILLION SILICON ATOMS

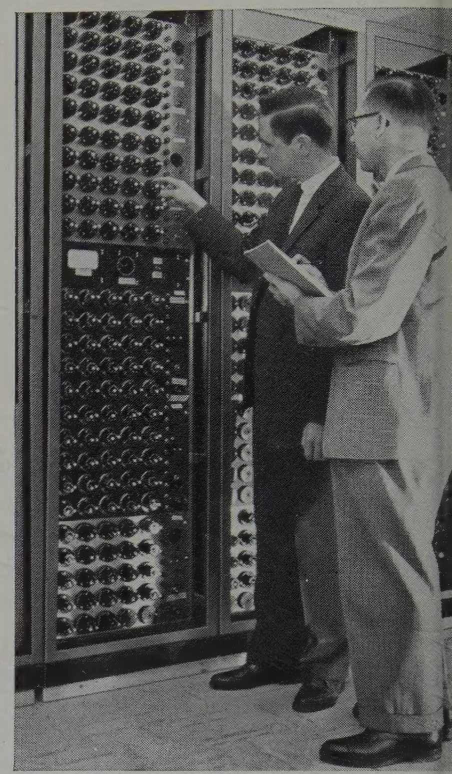
Circle No. 4 on Reader Service Card

One-million unit-hours without failure





G-E 2N43A LIFE-TEST DATA OBTAINED AT 1000-HOUR POINTS. Upper chart shows results of 100°C storage test (25°C storage test not shown). Lower chart shows results of 200 mw operating test. Broken lines in each chart indicate h_{fe}. Solid lines indicate I_{CBO} in microamperes. After 1000 hours of testing, there were no failures. The 2N43A transistor's high standard of quality is inherent in all G-E germanium PNP audio and switching transistors.



Dick Welch (left), Transistor Evaluation Engi and Lee Leinweber, Transistor Production E ing, take readings at cycled-life-test rack. In to electrical testing, G-E 2N43A transistors jected to all mechanical-test requirements in MIL-T-19500/18.

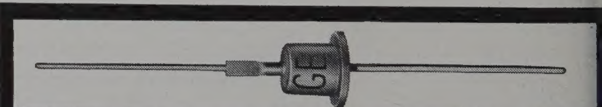
20% Safety Factor for silicon rectifiers aids designers

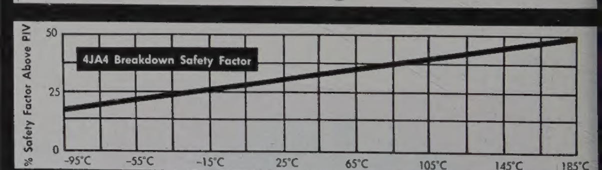
Designers who now apply their own safety factor to the published peak inverse voltage rating may avoid this step by using G-E low-current silicon rectifiers.

General Electric's PIV figures are set by allowing a 20% safety margin at −65°C. This margin is applied at the point of sharp breakdown voltage and increases with temperature until a maximum safety factor of 33% is reached at 150°C.

If you are derating published PIV figures to provide over-voltage protection, you may be buying costlier cells than you need, or, in series applications, more cells than necessary. Thus the built-in safety margin of G-E low-current silicon rectifiers could save you money. Note: This safety factor is provided for over-voltage protection only. Designs should, in all cases, be maintained within published maximum ratings.

This is only one reason why you should consider G-E low-current silicon rectifiers for all your power requirements. You'll find these devices more attractive to use than ever before—both in quality and price—with equally fine values in low-current silicon stacks. Stud-mounted units are also available. Ask your G-E semiconductor representative for the "big news" on low-current silicon rectifiers.





Maximum Ratings and Specifications

	PIV	RMS Voltage	Cont. Reverse D-C Volt	D-C Output (150°C Amb.)	D-C Output (50°C Amb.)	Ambient Operating Temp.
1N536-40, 1N1095-96 series	50-600	35-420	50-600	250	750	165
1N440B series	100-600	70-420	100-600	300-500 (100°C)	300-750	150-165
1N1487-92 series	100-600	70-420	100-600	250 (125°C)	750 (25°C)	140
1N1692-95 series	100-400	70-280	100-400	250 (100°C)	600 (50°C)	115
	volts	volts	volts	ma	ma	°C

for General Electric audio transistors

General Electric's 1958 process and quality-control advances were reflected in recent life-test results exhibited by G.E.'s line of germanium PNP audio transistors. Random samples of Type-2N43A transistors were subjected to rigorous mechanical testing . . . drop-shock, detergent-bomb, lead-fatigue (i.e., all the MIL-T-19500/18 mechanical test requirements). Then a total of 1050 Type 2N43A transistors were put on Life Test, with the following results:

350 (10 lots, 35 units each) were given a 100°C storage test for 1000 hours. No failures.

350 (10 lots, 35 units each) were given a 25°C storage test for 1000 hours. No failures.

350 (10 lots, 35 units each) were given a 200 mw cycled-life test for 1000 hours. No failures.

Engineering test data indicate that, without exception, parameters remained stable (see curves at left).

The G-E 2N43A transistor is representative of the outstanding quality built into General Electric's entire line of germanium PNP audio and switching transistors.

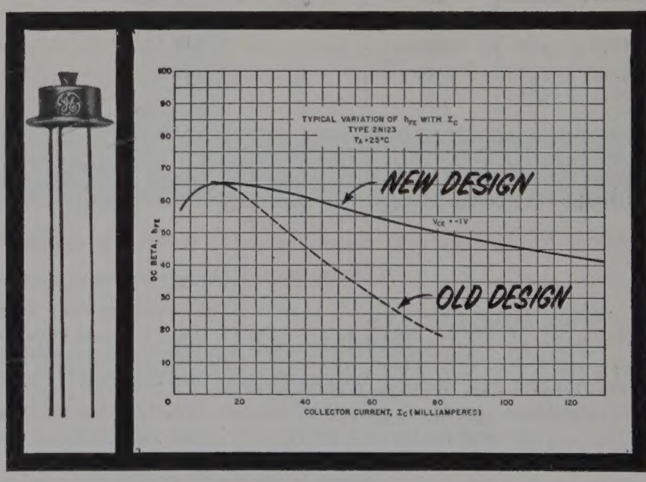
RATINGS: AUDIO AND LOW-FREQUENCY SWITCHING TRANSISTORS

		2N43	2N43A	2N44	2N44A	2N1056	2N1057	
Collector-to-base Voltage (25°C)	V_{CB}	—45	—45	—45	—45	—60	—45	volts
Collector-to-emitter V. (25°C)	V_{CE}	—30	—30	—30	—30	—75	—45	volts
Total Dissipation (25°C)	P_C	240	240	240	240	240	240	mw
Forward D-c Current Gain, Common Emitter I_C/I_B								
(V_{CE}=—1v; I_C= —20 ma)	h_{FE}	53	53	31	31	32	58	
(V_{CE}=—1v; I_C=—100 ma)	h_{FE}	48	48	25	25		52	
Collector Cutoff Current (V_{CBO}=—45v)	I_{CO}	—8	—8	—8	—8		—18	μa
(V_{CB}=75v; I_E=0)	I_{CO}	NOTE: All figures represent design-center ratings.				—18		μa

High frequency transistors modified for higher Beta

Recent design improvements in high frequency switching transistors (Types 2N123 and 2N450) have improved their d-c beta at higher collector currents. The result is higher gain and improved saturation characteristics at these high currents.

Refinements in quality control tests have also been put into practice on the production line. These units are affected: Types 2N123, 2N450 and the 2N396 series. Units are aged at 100°C for 96 hours to stabilize characteristics. All transistors are subjected to a high-pressure detergent test for hermetic sealing. D-C characteristics are warranted to be within the limits shown on specification sheets. As a result, these transistors are now widely accepted in missile computer work and other rigorous applications.



SEMICONDUCTOR PRODUCTS

SANFORD R. COWAN, Publisher

February 1959 Vol. 2, No. 2

Front Cover

This transistorized photoflash unit was engineered as a joint project between the FR Corporation of New York, and the Semiconductor Products Division of Bendix at Red Bank, New Jersey. This example of manufacturer-customer teamwork is a typical illustration of how the visualization of new products in various fields can result in increased semiconductor applications.

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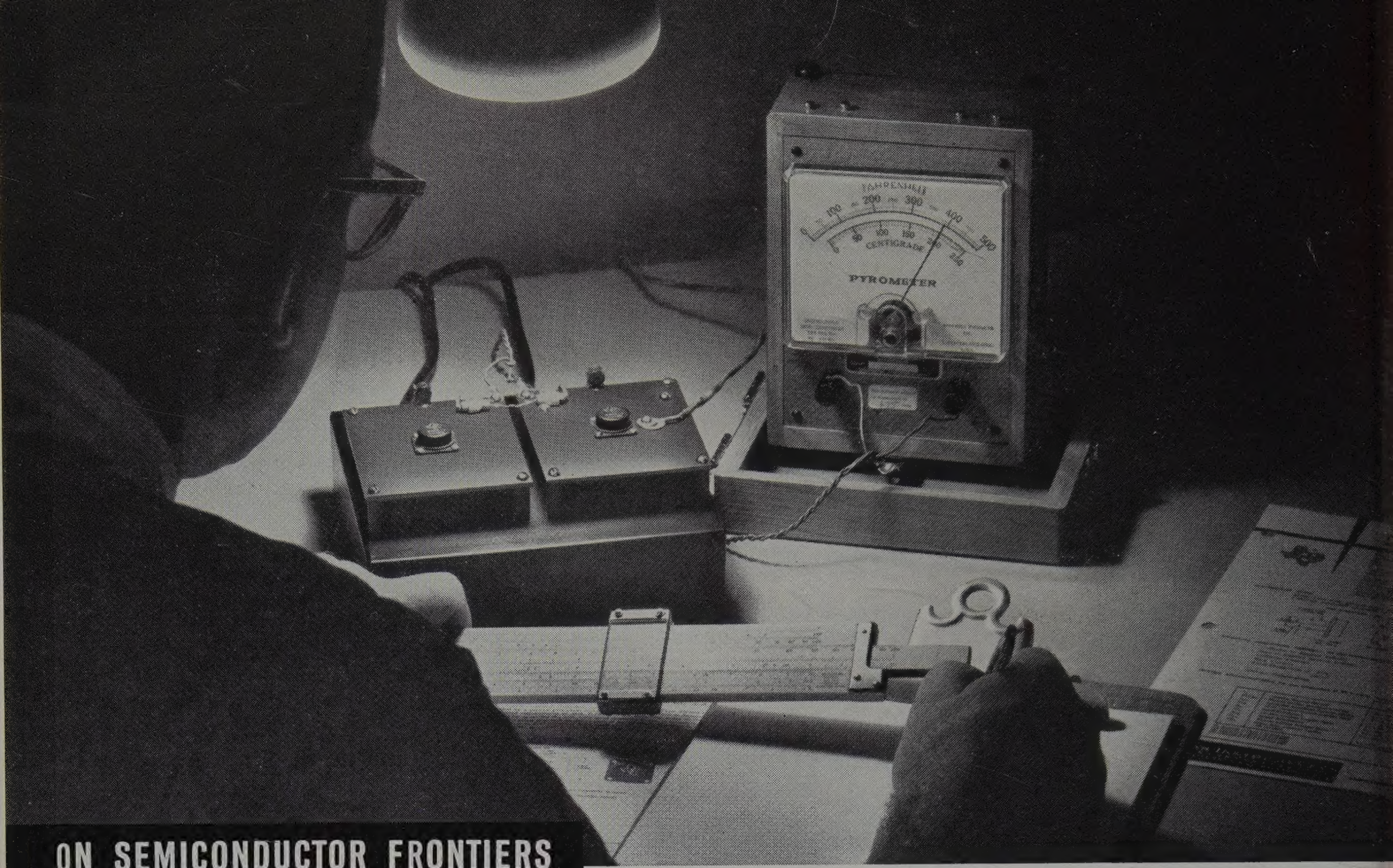
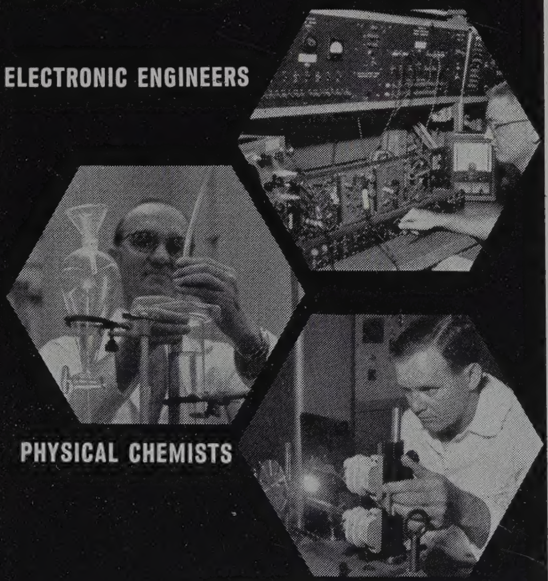
POSTMASTER: SEND FORM 3579 to SEMICONDUCTOR PRODUCTS, 300 West 43rd STREET, NEW YORK 36, N. Y.



ON SEMICONDUCTOR FRONTIERS

YOU can help 'beat the heat' at 200°C



ELECTRONIC ENGINEERS

PHYSICAL CHEMISTS

SOLID STATE PHYSICISTS

ELECTRONIC ENGINEERS at TI's Semiconductor-Components division are beating the heat barrier with devices operating at 200°C and higher — twice the boiling point of water! Under the hot glare of infrared light simulating extreme operating conditions, the engineer shown above is testing a TI-introduced silicon power transistor operating in conjunction with the new *Sensistor* temperature-compensating silicon resistor.

Exploration of new frontiers in solid state electronics is a never-ending project at TI's S-C division with engineers, physicists and chemists combining their research efforts to extend frequency, power and temperature limits -- building America's electronic future. If you are interested in joining other leading engineers and scientists at the industry's most modern research, development and production facilities — write or call for more information on Texas Instruments, a corporation nearly three decades old — recognized leader of the semiconductor industry.

Inquiries from experienced graduate engineers interested in furthering solid state electronic technology are welcomed by the TI Semiconductor-Components division. You can play a vital role in research or development engineering on:

transistors, diodes, rectifiers, capacitors, resistors, IR detector cells, materials purification, circuit design and application, test equipment design, and design of complex automatic machinery.

You will discover forward-looking personnel benefits more advanced than any other in the industry. For detailed information in confidence, write:

Harry Laur
Personnel Administrator

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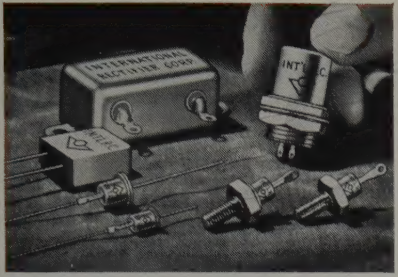
RECTIFIER NEWS



64 Zener Diode Types Offer Advantages to Every Voltage Regulator Circuit

As compared to other voltage reference elements, the silicon diode regulator has a longer life expectancy because of its mechanical ruggedness. It does not deteriorate under storage nor age during its operating life. Small size and light weight make its use in airborne or portable equipment especially desirable from many standpoints.

International Rectifier Corporation now offers an extensive line of zener types numbering 64 in seven basic styles. From the miniature type rated at 750 milliwatts to the precision 1N430 reference element types, all are manufactured to meet the most rigid military requirements. *See how these all-welded, hermetically sealed diodes can improve your circuit design. . . .*

CIRCLE 50 ON READER SERVICE CARD

HZ Series Silicon Zener Voltage Regulators Replace Vacuum Tubes — Streamline Circuitry — Take Only Half The Space!

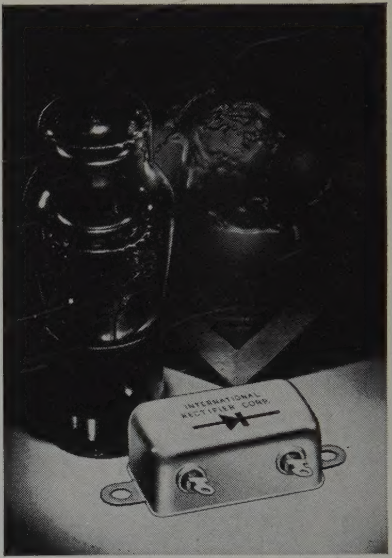
Semiconductor equivalents eliminate components and circuitry required by tube counterparts to overcome plasma oscillation and high firing potential.

Voltage regulation circuits can be simplified and the reliability increased by using silicon zener voltage regulators in place of conventional gas tube regulators such as the 0A2, 0A3, 0B2, 0C3, 1B46 and the 991.

The International Rectifier HZ series, provides a substantially lower dynamic resistance than do comparable tube types — and over a much broader temperature range (—65°C to +165°C). This feature, and the unusually high zener reference voltage, stem from the unique construction of these units. Mechanical ruggedness of this package leads to longer term reliability than can be expected from tubes.

Other regulators restrict the engineer to a few specific voltages within a very limited current range. Not so with the HZ series. You may select the *exact* zener voltage your circuit requires within a range of from 24 to 160 volts — over a wide range of current values. This opportunity to select in discreet voltage steps obviates additional corrective circuitry . . . saves time!

If you are developing a voltage regulation circuit, write or call us today. We will be happy to provide whatever assistance you need to improve your circuit with silicon zener regulators.



For Bulletin SR-253 describing the HZ series in technical detail . . .

CIRCLE 52 ON READER SERVICE CARD

ZENIAC Provides a Shortcut to the Application of Silicon Zener Diodes

A flip of the Zeniac selector switch quickly tells you the exact diode required in complex breadboard circuitry. This unique innovation — the first semiconductor substitution box in history — has been designed specifically to aid system design groups by saving valuable lab time in the application of zener diodes. The eleven component diodes of Zeniac are rated at 1 watt and range in voltage from 3.6 to 30 volts. Zeniac is available at your local International Rectifier Industrial Distributor. For details on this time saver . . .

CIRCLE 51 READER SERVICE CARD

Technical Service Provides XY Plot of Reverse Breakdown Characteristics of Each Diode in all Prototype Orders

To eliminate guesswork and tedious testing on your part, every zener diode sent on prototype orders will be accompanied by a specially plotted XY recording of its exact breakdown voltage point! This permanent record can come in mighty handy when it's time to match diodes or reorder to the same specs. This is just one of the many application engineering services we are prepared to extend to you at all times!

Write on your letterhead *for Bulletin SR-250-A, a four page technical article describing the characteristics of zener diodes, how to select them, and application data with circuit schematics.*

FOR SAME DAY SERVICE ON PRODUCT INFORMATION DESCRIBED ABOVE, SEND REQUEST ON YOUR COMPANY'S LETTERHEAD

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Editorial . . .

The Magneto-Resistive Effect

Many novel applications of the magneto-resistive effect can be predicted in the foreseeable future. This effect, is one in which the electrical resistivity of a specimen of semiconductor or metal varies as a function of the applied magnetic induction B. The effect can be made very pronounced by using high mobility compound semiconductors, such as indium-antimonide and indium-arsenide. The relationship between the resistivity and the magnetic field is generally expressed as $\rho\ (B) = \rho_o\ (1 + C\mu^2B^2)$, where ρ_o is the resistivity in the absence of the external magnetic field, μ is the carrier mobility, and C is a proportionality factor depending upon the angle between the electric and magnetic fields. The change in resistivity is normally opposed by the coexistent Hall effect, whose transverse field tends to balance the average transverse force due to the magnetic induction field. With samples of appropriate geometry (a disc with radial current flow, or an elongated rectangle with current flow parallel to the short side) the effect is enhanced. For example, in indium-antimonide samples resistance variations of up to 60 to 1 can be obtained with magnetic induction varying from zero to 2 Wb/m^2. (Weber per square meter).

The principal application of the magneto-resistive effect so far has been in the field of measurement of magnetic flux. However, uses as computing elements, microphones or pick-ups, switches, audio amplifiers, rectifiers, and thickness or stress gauges have been predicted. For example, it appears that magneto-resistive pick-ups can be built with enough output power to directly drive a loudspeaker. Similarly, switches with a back-to-front ratio of 1000:1 can be designed. These may be obtained by utilizing the fact that the sense of the deviation of electrons and holes may be reversed with the reversal of the electric field thereby bringing the carriers on to one side or on to the other side of the specimen. These sides may be made to possess different recombination rates by appropriate etching procedures. This type of magnetic relay has the interesting property in that the switched and switching circuits are not ohmically interconnected. Such a property is of interest in the design of switching networks with a minimum of components.

Semiconductors and Biology

Bell Telephone Laboratories reports the development of a simple electronic circuit using semiconductors which simulates some functions of the individual biological nerve cell, or neuron. The nerve cell function—transmission of electrical pulses in response to stimuli, and only to those stimuli that meet certain conditions—has been simulated by a simple circuit. This, and other similar developments, may lead to better understanding and prediction of neurological behavior. A complete scientific article on this subject is now in preparation and will appear in a forthcoming issue of SEMICONDUCTOR PRODUCTS.

Awards Progress

Details of the SEMICONDUCTOR PRODUCTS awards for the most outstanding article on semiconductor circuit design, and the most outstanding nomograph relating to semiconductor circuit design may be obtained by turning to page 42.

Correction

Our attention has been called to a typographical error in the table on page 18 of the article, "Making and Using the Satellite RF Transistors," by W. C. Pilkington, E. A. Temple, and H. G. Wells, published in the November/December 1958 issue. The corrected table is as follows:

		2N509	*2N537*	
Breakdown Voltages:				
	BV_{cb}	30	30	Volts
	BV_{eb}	—	1	Volts
Alpha		0.97 (min.)	0.9 (min.)	
100 mc Common Emitter Current Gain	h_{fe}	15 (min.)	10 (min.)	*db*
Collector Power Dissipation:	P_c	200	200	*mw*

The error involved the numbers 30—30 and 1 which were interchanged.

Samuel L. Marshall

Circle No. 7 on Reader Service Card

GRACE SILICON

(ultra-high-purity)

"For want of a nail the battle was lost" becomes painfully true when translated to lack of purity in the semi-conductor material you choose for your transistors, diodes or other silicon devices.

The Pechiney process, used in the manufacture of Grace Silicon, is noted for a product with low boron content as well as overall high purity.

May we suggest that whenever top quality silicon is desired—silicon combining both high purity and uniform quality—you get in touch with GRACE ELECTRONIC CHEMICALS, INC., at PLaza 2-7699, 101 N. Charles Street in Baltimore.

GRACE ELECTRONIC CHEMICALS, INC.

101 N. Charles St., Baltimore, Maryland
Subsidiary of W. R. GRACE & CO.

Circle No. 9 on Reader Service Card

Transistor Noise Factor Tester

JAMES J. DAVIDSON*

The need for a simple and reliable equipment for measuring the audio Noise Factor of transistors has long been obvious. Previous equipment has been complex and tedious to use, making the measurement difficult, and subject to error by inexperienced personnel. In addition, special auxiliary equipment requirements, such as a noise diode and a thermal voltmeter, has limited the use of such equipment, even in the laboratory.

The equipment to be described overcomes the above limitations. It is completely self-contained except for an auxiliary sine-wave oscillator and Ballantine Voltmeter. Once it is set up and calibrated, the measuring procedure is a two-step process of adjusting the output to a predetermined amount and pressing a button to obtain the Noise Factor reading directly.

OF THE most common methods of measuring Noise Factor (signal generator or noise diode), the signal generator method is the more satisfactory for general use. The reason is that accurate and stable generators are commonly available as laboratory equipment, while satisfactory audio noise diodes are not. The generator method, however, requires accurate knowledge of several quantities; the thermal noise of the source resistance, the noise bandwidth, and the gain of the system must all be determined.[1]

To simplify testing, it is desirable that the above quantities either be fixed or readily adjusted, and that all computation be eliminated. This is accomplished in the following manner:

The noise bandwidth of the system can be accurately controlled by the use of sufficient frequency selective feedback. Practically all bandwidth variation due to differing transistor parameters can be eliminated in this way.

Once a value of source resistance is chosen, and the noise bandwidth is known, the source thermal noise can be calculated. This value is fixed.

By feeding a signal to the input which bears a known relationship to the source thermal noise, the absolute value of gain becomes unimportant. The output can be adjusted to any convenient level, since it is the degradation in source signal-to-noise ratio which is to be measured. By removing the signal input, the degradation can be measured directly, and this value is the Noise Factor of the amplifier under test.

Theory of Operation

The open circuit root-mean-square thermal noise voltage of a resistor by Nyquist's formula[2, 3, 4] is

$$\sqrt{\overline{e^2}} = \sqrt{4kTRB_{eq}}$$

where

k = Boltzmann's Constant = 1.38×10^{-28} (joule/°K)
T = Kelvin Temperature (°K)
R = Resistance (ohms)
B_{eq} = Equivalent Noise Bandwidth (cps)

* Advanced Development Section, RCA Victor Radio and "Victrola" Division, Camden, New Jersey.

The equivalent noise bandwidth (B_{eq}) is the bandwidth of the idealized passband. That is, a rectangle with the same height and total area as the actual passband. If the passband is determined by a low pass network with a *single reactive element,* with time constant RC, the gain will be down 3 db at a radian frequency

$$\omega_o = \frac{1}{RC}$$

In this case B_{eq} can be determined by integration of the normalized *power* transfer function. The *voltage* transfer function is

$$T(\omega) = \frac{\frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} = \frac{1}{1 + j\omega RC}$$

The magnitude of the voltage transfer function is

$$|T(\omega)| = \frac{1}{\sqrt{1 + \omega^2 R^2C^2}}$$

The normalized power transfer function is

$$|T(\omega)|^2 = \frac{1}{1 + \omega^2 R^2C^2}$$

Integrating

$$B_{eq} = \int_o^\infty \frac{d\omega}{1 + \omega^2 R^2C^2} = \frac{1}{RC} \tan^{-1} \Big[\omega RC \Big]_o^\infty$$

$$= \frac{\pi}{2RC} \text{ radians/sec} = \frac{1}{4RC} \text{ cycles/second}$$

Since

$$\omega_o = \frac{1}{RC}$$

therefore,

$$\frac{B_{eq}}{\omega_o} = \frac{\pi/2RC}{1/RC} = \frac{\pi}{2} = 1.57$$

Thus, the equivalent noise bandwidth for a system which rolls off at 6 *db* per octave is 1.57 times the 3 *db* bandwidth. If the 3 *db* point is set at 10 *kc*, the noise bandwidth is 15.7 *kc*.

Using the value of 15.7×10^3 for B_{eq}, and considering the optimum source resistance for a transistor as 1500 ohms, the open circuit thermal noise voltage of the source resistance at 300° Kelvin temperature is

$$\sqrt{\overline{e_n^2}} = .627\ \mu v$$

The choice of 1500 ohms for the optimum source resistance for minimum Noise Factor is based on a number of measurements on low noise transistors. The curves in *Fig. 1* show that the optimum value is fairly constant for several types of transistors.

Having determined the noise generated by the source resistance, it is evident that this noise will be amplified and appear at the output. Any extraneous noise in the amplifier will also be amplified and appear in the output, adding to the noise from the source resistance. The ratio between the total output noise and that part from the source resistance alone is the Noise Factor of the amplifier.

To separate the source noise from the amplifier noise, it is necessary to know the gain. This is most easily accomplished by feeding a known signal to the input and measuring the output. A suitable method for testing would be to feed a signal to the input which bears a fixed relationship to the source noise. If, for example, the known signal is exactly 10 times the source noise, then the specific value of gain is unimportant, and the gain can be adjusted so as to give any convenient output. Then, when the signal is removed, anything less than a 20 *db* drop in output is because of excess amplifier noise. If the scale of the output meter is calibrated in *db*, the Noise Factor can be read directly in *db* up to 10 *db*. Above 10 *db* Noise Figure the reading becomes increasingly less accurate, due to the vector relationship between the signal and noise voltages. That is, the output voltage with signal is

$$e_{o_1} = |G| \sqrt{\overline{e_s^2} + \overline{e_n^2} + \overline{e_a^2}}$$

where

G is the mid-band gain of the amplifier,

e_s is the known signal input,

$\overline{e_n^2}$ is the mean square source noise, and

$\overline{e_a^2}$ is the mean square amplifier noise.

When the signal is removed, the output drops to

$$e_{o2} = |G| \sqrt{\overline{e_n^2} + \overline{e_a^2}}$$

Since e_{o1} is arbitrarily set at 10 on the output meter, the (numerical) Noise Factor that the tester will measure is

$$F_M = \frac{10 e_{o2}}{e_{o1}} = \sqrt{\frac{100\ \overline{e_n^2} + 100\ \overline{e_a^2}}{\overline{e_s^2} + \overline{e_n^2} + \overline{e_a^2}}}$$

But since e_s has been chosen as

$$10 \sqrt{\overline{e_n^2}},$$

$$F_M = \sqrt{\frac{100\ \overline{e_n^2} + 100\ \overline{e_a^2}}{101\ \overline{e_n^2} + \overline{e_a^2}}} = \sqrt{\frac{\overline{e_n^2} + \overline{e_a^2}}{\frac{101}{100}\overline{e_n^2} + \frac{1}{100}\overline{e_a^2}}}$$

But the true Noise Factor (by definition) is

$$F = \frac{|G| \sqrt{\overline{e_n^2} + \overline{e_a^2}}}{|G| \sqrt{\overline{e_n^2}}} = \sqrt{\frac{\overline{e_n^2} + \overline{e_a^2}}{\overline{e_n^2}}}$$

The ratio of the true Noise Factor to the indicated Noise Factor is

$$\frac{F}{F_M} = \sqrt{\frac{\overline{e_n^2} + \overline{e_a^2}}{\overline{e_n^2}} \times \frac{1.01\ \overline{e_n^2} + .01\ \overline{e_a^2}}{\overline{e_n^2} + \overline{e_a^2}}} = \sqrt{1.01 + .01 \frac{\overline{e_a^2}}{\overline{e_n^2}}}$$

As is evident from this equation, when the amplifier noise is large compared to the source noise, the ratio of the true to measured Noise Factor deviates from unity. A plot of the relationship in decibels is shown in *Fig. 2*. It can be seen that the measured Noise Factor is about 0.5 *db* low at 10 *db*, and 1 *db* low at 14 *db* true Noise Factor. For measurements above 10 *db*, the generator voltage e_s can be increased by 20 *db*, which will give accurate measurements up to 30 *db* Noise Factor. Beyond this point it is extremely difficult to get accurate readings under any circumstances, since transistors which are this noisy show wide fluctuations in noise output with time. However, measurements can be made up to 50 *db*, beyond which the second stage overloads.

Voltmeter Corrections

Up to this point, the tacit assumption has been made that the indicating voltmeter reads true *rms* voltage. While such instruments are available, their limitations make them unsuitable for general use. For example, a thermocouple type voltmeter is quite fragile, and suffers from high frequency limitations. As a result, most laboratory voltmeters are average reading types, calibrated for the *rms* value of a sine wave. The Ballantine models 300, 310A, and 314 fall into this category. Since the response of an average reading voltmeter is different to sine waves and noise,[5] a correction factor must be introduced.

L. L. Beranek, in his book "Acoustic Measurements"[6] has an excellent discussion of the response of meters to simple and complex tones. The information given here is taken from Chapters 10 and 11.

The equation representing the law of normal frequency distribution in random processes is

$$P\ (x) = k\ e^{\frac{-x^2}{2\sigma}}$$

where P is the probability density as a function of x. When P is integrated between the limits of $-\infty$ and $+\infty$, the result must be unity, since the probability is 100% that x will lie between these limits. The constant k, therefore is of such a value as to satisfy this condition.

Without going through the mathematics, σ is the root-mean-square deviation of the random process. In

the case of electrical noise it represents *rms* voltage or current. The value of the *average* deviation (average current or voltage) is

$$a = \sigma \sqrt{\frac{2}{\pi}} = 0.798\, \sigma$$

Therefore the ratio of *rms* to average value of noise is 1.25 times, or 1.96 decibels.

For a sine wave the ratio of *rms* to average is

$$\frac{rms}{av} = \frac{1/\sqrt{2}}{2/\pi} = 1.111$$

or 0.91 decibels. Therefore, if two meters, one *rms* and the other average indicating, are calibrated to read alike on sine waves, then on random noise the average meter will read 1.05 *db* lower than the *rms* meter.

This correction of 1.05 *db* (1.13 times), can be included in the value of the calibrating signal. Rather than making the calibrating signal exactly 10 times the thermal noise voltage, it can be made 10/1.13 = 8.85 times (18.95 *db*) above the noise. This will correct for the difference in response over the entire range of readings.

Circuit Description

Frequency Response

In order for the circuit to operate as outlined in the previous section, the frequency response must be controlled. The two major problems are: making the rate of roll-off of the entire amplifier 6 *db* per octave; and making the 3 *db* point at the same frequency regardless of the type of transistor under test. Both of these requirements can be met by the proper use of feedback. Fourteen *db* of feedback is applied from the second stage to the input of the transistor under test. This effectively flattens the response of these stages out to 100 *kc*. Frequency selective feedback is applied to the third stage, at 6 *db*/octave, starting at 10 *kc*, giving the secondary advantage of low output impedance at high frequencies.

Fig. 3 shows the measured high frequency response of the tester. Although the response is down 1 *db* at 100 *kc* from the ideal curve, the integrated area is nearly identical to the ideal. This is shown more clearly in *Fig. 4*, where both amplitude and frequency are plotted linearly. It is evident that the area contribution above 100 *kc* is small. Indeed, if the entire area above 100 *kc* were eliminated, the error in noise bandwidth would be only 6.4%, making a difference of less than 0.3 *db* in the Noise Factor. Since the actual area loss is considerably less than this (about 2%) the correction is negligible (about 0.08 *db*). Therefore, the 3 *db* point can be set once at 10 *kc*, and the noise bandwidth can thereafter be assumed to be 15.7 *kc*. The integrated area (B_{eq}) is shown by the dotted line in *Fig. 4*.

The low frequency response is down 3 *db* at about 20 cycles, and is slightly dependent on volume control

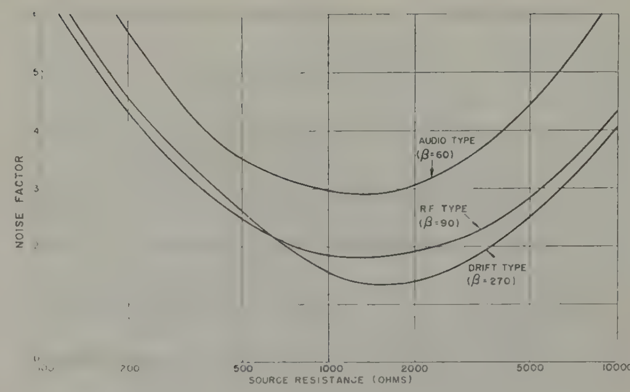


Fig. 1—Noise Factor vs. Source Resistance, Selected Transistor of each type

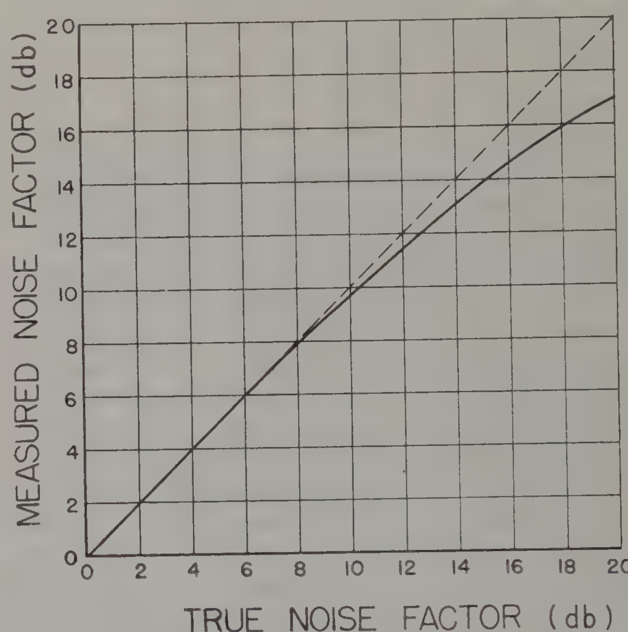


Fig. 2—True vs. Measured Noise Factor

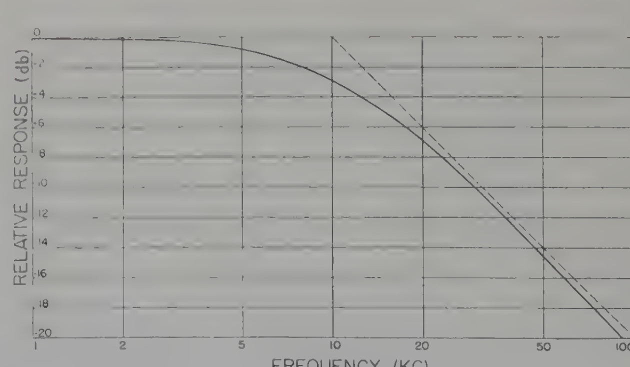


Fig. 3—Frequency Response (Log Scale)

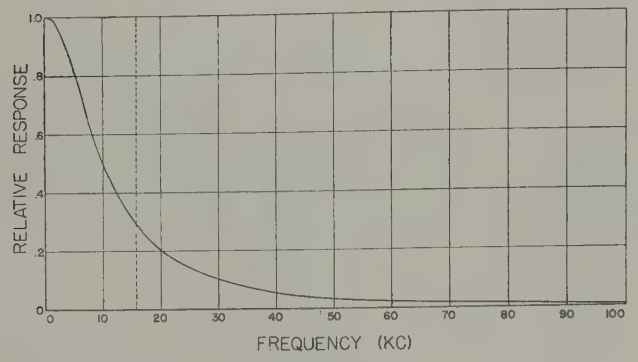


Fig. 4—Frequency Response (Linear Scale)

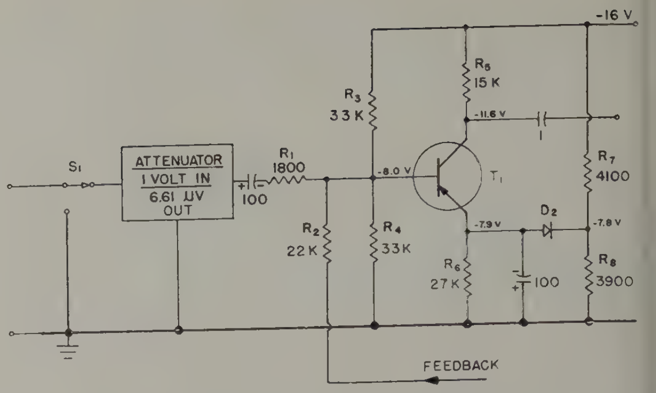


Fig. 5—Simplified first stage schematic

setting. The roll-off point is determined by the coupling capacitor between the second and third stages (see *Fig. 6*). If extended low frequency response is desired, the coupling capacitor can be increased from its indicated value of 0.5 μf. Each doubling of this value will give approximately another octave on the low end.

Surge Currents

To simplify operation as much as possible, it was necessary to design enough stability into the circuit to make metering of the operating point unnecessary. The operating point was set at $I_E = 0.3\ ma$, $V_{CE} =$ 3.5 volts, which generally fulfills the requirements for lowest noise. Reasonable amounts of temperature stability require large capacitors in order to keep the *a-c* gain high. Since the first transistor is to be plugged in for test, these capacitors, in charging through the transistor, can alter its characteristics. To avoid this, a clamp is placed on the emitter capacitor, keeping it charged when the transistor is pulled out.

Fig. 5 shows a simplified schematic of the first stage. Diode D_2 is reverse biased when the transistor is in. When the transistor is pulled out, the voltage at the emitter terminal starts to drop, forward biasing the diode. The voltage to which the emitter terminal drops is determined by R_6, R_7 and R_8, and is about 7.3 volts. The base terminal is held at 8.0 volts by a heavy bleeder, so that the charge on the input capacitor does not change. Although the voltage at the collector terminal rises to —16V when the transistor is pulled out, the coupling capacitor is small enough that the charging current does no damage. Thus, it is permissible to insert the transistor to be tested while the power is on. In fact, the power should be on for at least one minute before the transistor is inserted. The charging currents when the power is turned on are quite large, and can damage the transistor if it is in the circuit. The transients die away in less than a minute, after which transistors can safely be inserted in rapid succession for test.

Switching

In order to test both *p-n-p* and *n-p-n* transistors, the voltages on the socket must be reversed. This is done by switch S_1 in *Fig. 6*. The center position is off. Turning in one direction grounds the emitter resistor and connects the collector resistor to B— for *p-n-p* units. The other direction grounds the collector resistor and connects the emitter resistor to B— for *n-p-n* transistors.

The base voltage is maintained at a constant 8 volts by the matched 33K resistors regardless of the position of the switch. However, the emitter voltage is —7.9 volts for *p-n-p*, and —8.1 volts for *n-p-n* transistors. Furthermore, when the transistor is out of the socket, the emitter terminal drops toward ground potential with S_1 in *p-n-p* position, but rises toward B— in the *n-p-n* position. Therefore, two diodes are necessary to limit surge currents. D_1 prevents the emitter terminal voltage from rising above —8.7 volts for *n-p-n's* and D_2 prevents it from dropping below —7.3 volts for *p-n-p's*.

Source Impedance

The source impedance that the base sees is important in measuring Noise Factor (see *Fig. 1*). If a value of 1500 ohms is chosen as optimum, the biasing and feedback resistors must be included. Thus, while R_1 is 1800 ohms, combining this with R_2, R_3, and R_4 in parallel yields 1510 ohms.

Calibrating Voltage

Since the open circuit thermal noise voltage can be represented by a noise voltage generator in series with a noiseless resistor, the calibrating voltage is introduced in the same way. By inserting a 10 ohm resistor in series with the ground lead of the source resistor (R_1 in *Fig. 5*), and feeding an oscillator to the point, a good approximation to a pure voltage generator in series with the source resistor is achieved. The advantage to this method is that the calibrating oscillator can be inserted or removed without affecting the circuit operation in any way. As indicated in the section on theory, the calibrating voltage should be 8.85 times the thermal noise voltage to compensate for voltmeter characteristics. Since the source resistance is 1510 ohms, the thermal noise is .627 μv. The calibrating voltage delivered to the base of the transistor must then be 5.55 μv. However, the voltage divider formed by R_1 in series with the parallel combination of R_2, R_3

and R_4 (9.44 K) means that the attenuator output must be $\frac{11.24}{9.44} \times 5.55 = 6.61$ μv.

The attenuator is designed so that 1 volt delivered to the input terminals gives the required 6.61 μv in series with R_1. Since this is an attenuation of 103.6 *db*, the divider has two legs, to minimize stray effects (capacity feedthru, primarily). The values are so chosen that if each resistor has exactly the resistance shown in *Fig. 6*, the division will be exactly right.

Construction Details

Special care is required in the construction of the noise tester. Since the equivalent thermal input noise is under 1 microvolt, and any interference greater than 0.1 microvolt will materially alter the readings, careful attention to details is necessary, at least in the first stage. Proper grounding and shielding are particularly vital to avoid stray pickup and regeneration.

Physical Layout

The entire noise tester was built into a 4″ x 4″ x 2″ steel box, as shown in *Fig. 7*. Internal views are shown in *Fig. 8*. The entire attenuator, including switch *S2* is built into a separate shield can. This is required to prevent the large generator voltages and currents from coupling into the input circuit.

In wiring the switch S_2, where several connections are made to the same terminal lug, connect the generator leads closest to the body of the switch. Since better than 100 *db* of attenuation is required, the common impedance of ¼″ of ground bus can throw the calibration off. By connecting the generator leads physically closest to the switch body, common coupling in the various legs of the attenuator is avoided.

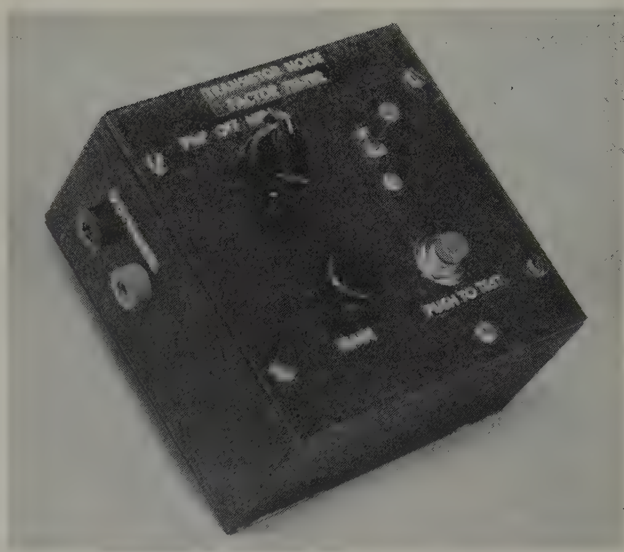


Fig. 7—Transistor Noise Factor Tester

The input stage is built on the front panel of the steel box, and the remainder is built on a "peg board." The board is held in place by the mounting bolts on switch S_1. The ground bus mounted on the board must be firmly connected to ground on the front panel.

Electrical Components

Several of the electrical components in the first

Parts List

PNP-Off-NPN Switch (S_1) (3P, 3T); Centralab #PA 1007
Push-to-Test Switch (S_2) (SP, DT); Switchcraft #103 SW
Gain Control (10K); Ohmite #CU-1031
Box 4″ x 2″ x 2″ Steel; Bud #CU-883
Amplifier Board Alden #650 ATMS-B
Trimmer 7-45 mmf Centralab #822 BN
Diodes G.E. 1N91
Input Capacitor 100 mf, 25wvdc

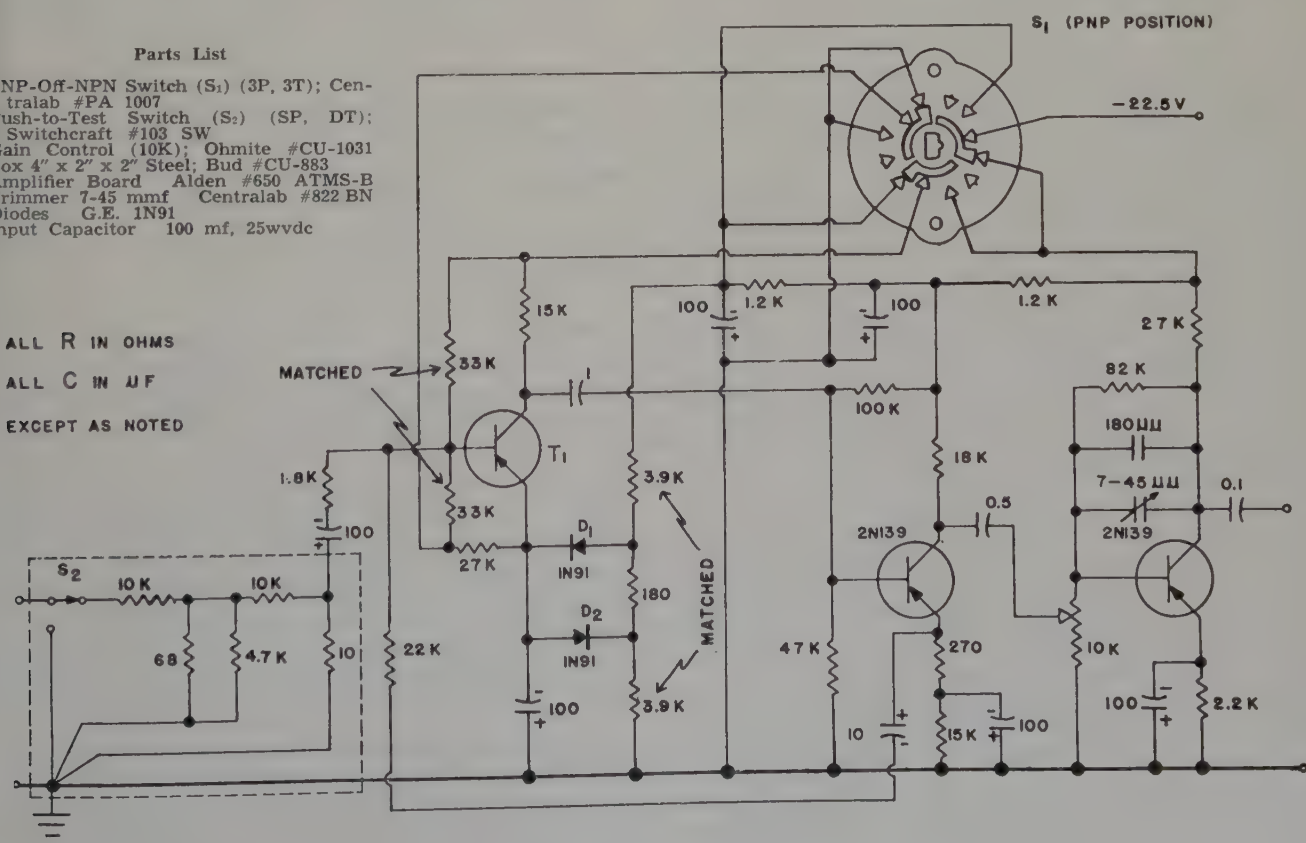
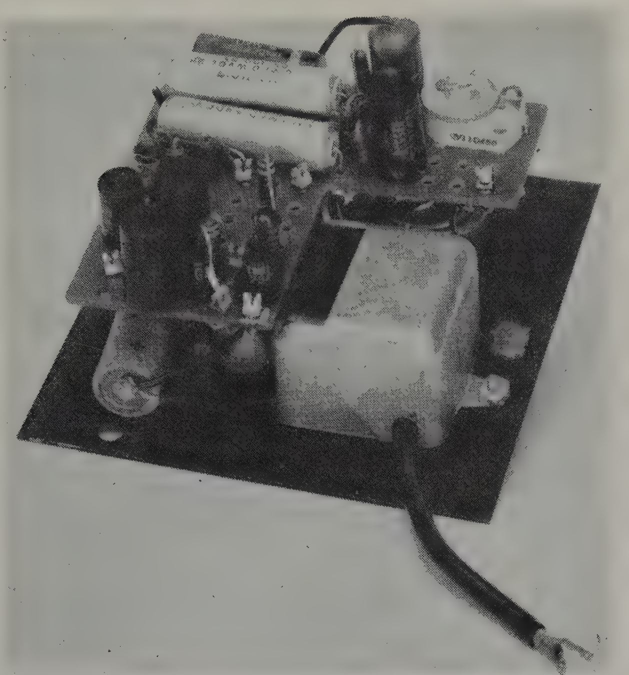


Fig. 6—Complete schematic



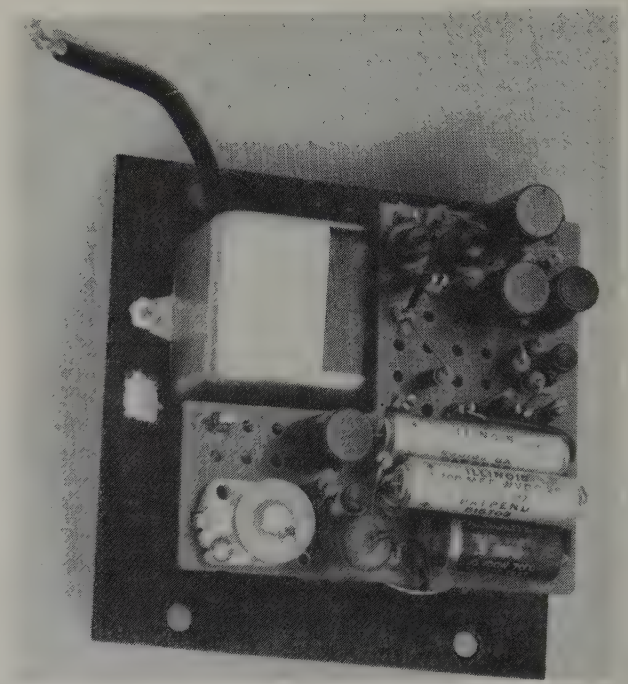


Fig. 8—Internal Views of the Noise Tester

stage are subject to excess noise, so that selection becomes necessary. The major offenders are the 100 μf input capacitor and the 33 K base biasing resistors. Because of the *d-c* potential across these components, they tend to produce low frequency fluctuations which may give entirely false readings. For this reason these components should be selected with considerable care. It is recommended that a quantity be available to test from. Since a total of six 100 μf capacitors are used in the Noise Tester, at least one should be quiet enough to use on the input. All capacitors except the second and third emitter bypasses are rated at 25 volts.

A rough check can be made on the quality of the input capacitor in the following way: Polarize the electrolyte by placing the capacitor across a 22.5 volt *d-c* source for about 15 minutes. Remove the voltage and short the capacitor for 15 minutes more. Then reconnect to the voltage source and measure the leakage current drawn through the capacitor. The current should rapidly settle down to a value of 20 microamps or less. This test does not guarantee low noise, but it eliminates the obviously bad units. The capacitor should be further checked in the circuit.

CAUTION—Short out sensitive micro-ammeters when connecting the capactor to the test voltage.

The noise produced by the second stage transistor must be low for accurate readings. The test to insure low second stage noise is simple. Leaving the first transistor (T_1) out, monitor the output voltage with a voltmeter. Select a transistor for the second stage which gives an output reading of less than 600 microvolts. The third stage noise generally is not a problem.

Operating Instructions

1. Turn the power on at least 1 minute before inserting the transistor to be tested.
2. Connect a 400 cycle oscillator to the input terminals, adjusting the oscillator voltage to 1 volt *after* connecting.
3. With a Ballantine 310A or equivalent voltmeter connected to the output, adjust the gain control to give 10 *mv* output (Ballantine on .01 scale).
4. Press pushbutton switch S_2 and read Noise Factor in *db* directly on the voltmeter scale.

When the indicated reading is greater than 10 *db*, the accuracy decreases (see *Fig. 2*). When this occurs, simply adjust the oscillator (step 2) to 10 volts, and proceed as before. It is now necessary to add 20 *db* to all readings (step 4).

Acknowledgement

The author wishes to express his thanks to L. Robert McCleary for his assistance in laying out and constructing the Noise Factor Tester.

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Transistor Switching Circuits

Part 2

A. W. CARLSON*

This installment describes a nonsaturating flip-flop circuit that may be used as a frequency divider. The concluding section on switching circuits concerns blocking oscillators. The blocking oscillator is one of the more frequently used switching circuits having the advantage of relatively simple circuitry. Design of blocking oscillators is thoroughly covered, including precaution to prevent destruction of transistors, and illustrated with five circuits.

A NONSATURATING flip-flop circuit is shown in *Fig. 9*. In a flip-flop circuit one of the transistors is conducting and the other is cut off. The roles of the conducting and cutoff transistors are interchanged by application of trigger pulses. If the trigger pulses are applied alternately to first one transistor and then the other, the circuit may be used to divide by two.

The required relationships between the circuit and transistor parameters are quite simple. The requirement that one transistor be conducting and the other be cutoff yields

$$R_1/R_L < \beta - 1, \qquad (9)$$

where β is the large signal collector-base current gain, R_L is the collector load resistance, and R_1 is the cross-coupling resistance.

The reverse bias at the base of the *off* transistor is given by

$$V_b\ off = \frac{-V_{BB}\, R_1}{R_1 + R_2} \qquad (10)$$

provided the *on* transistor is driven all the way on. The amount of reverse bias at the *off* transistor is an indication of the voltage required to trigger the circuit. The larger the reverse bias, the larger the trigger needed. This is the voltage to be overcome by the trigger at the base of the *off* stage. This is not the value of trigger voltage needed however, for by triggering so as to turn off the *on* stage (rather than turning on the *off* stage directly), the gain of the *on* stage may serve to reduce the trigger required. Further, as the trigger pulse width is reduced, the trigger voltage must be increased due to the finite frequency response of the transistors. The reverse bias should not be so small that the circuit will be triggered by noise, or allow the base circuit to become forward biased due to an increase in I_{CO} at higher temperatures. (I_{CO} has been assumed to be negligibly small.)

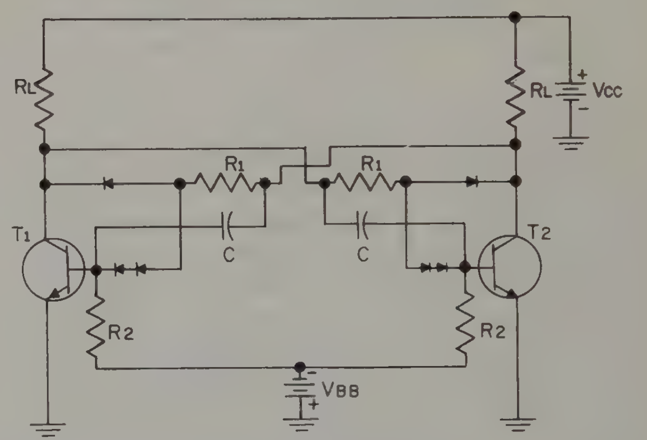

Fig-9 Nonsaturating Flip-Flop (Transistor Switch Circuits)

The *on* transistor is driven fully on when the following inequality is met:

$$\beta\left(\frac{V_{CC}}{R_1 + R_L} - \frac{V_{BB}}{R_2}\right) > \frac{V_{CC}}{R_L} \qquad (11)$$

The output voltage swing is given by

$$\Delta V_C \approx \frac{V_{CC}\, R_1}{R_1 + R_L} \qquad (12)$$

where ΔV_C is the difference between the on and off collector voltage.

Relationships (9) and (10) may be used to establish the *d-c* design of the flip-flop. When the circuit is

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to be switched rapidly, there are other considerations. For high speed operation, the collector load resistance should be small, of the order of a kilohm for example, to minimize the effects of collector capacitance and stray capacitance in slowing down switching times. It is also desirable that the voltages across the coupling condensers, C, return to their quiescent values between trigger pulses; this means that R_L, R_1 and R_2 should be small or else C should be. This is not a necessity, but is desirable since, for a given trigger pulse width, the magnitude of pulse required will increase rapidly as the pulse repetition frequency is increased above that frequency which just gives the coupling condensers time to recover from switching transients.

The coupling condensers serve two functions:

1) they speed up the switching transient by increasing the drive on the transistors during the initial part of the switching process;

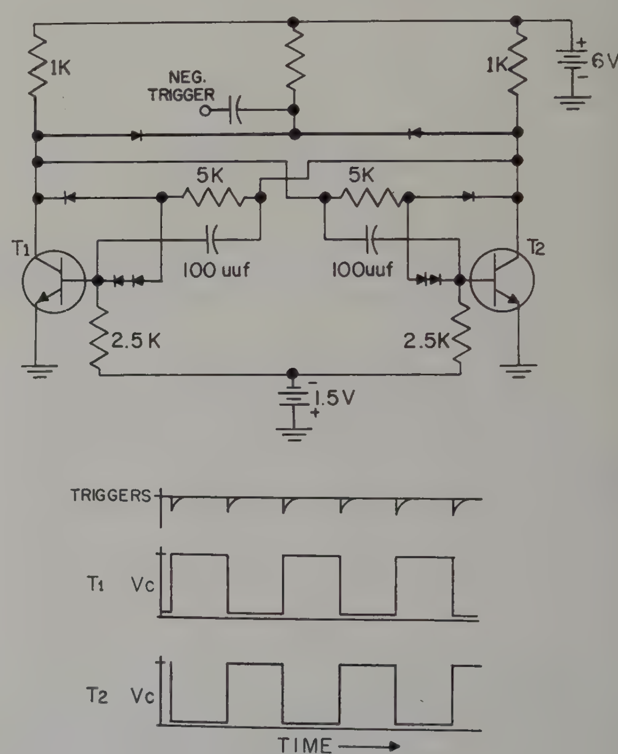
2) they prevent the circuit from flipping back and forth if the trigger pulse duration is longer than the switching transient, when the flip-flop is being used as a counter.

The circuit of *Fig. 9* is shown as a nonsaturating type. For low frequency applications with trigger pulses of sufficient duration available, the circuit may be made saturating by omitting the diodes and connecting the base sides of the cross-coupling resistors, R_1, directly to the appropriate bases.

As an example, suppose a flip-flop is to be designed having the following characteristics: a 5 volt output voltage swing with a collector supply of 6 volts, a reverse bias of 1 volt at the *off* base with a 1.5 volt bias supply. The circuit is to be operated at a relatively high pulse repetition frequency and to minimize effects of capacitive loading, the collector load resistance is to be 1 kilohm. The transistors are to have a large-signal beta of greater than 30.

From Equation (12) R_1 is determined to be 5 kilohms. The ratio R_1/R_L is 5, which is less than 29, thus satisfying inequality (9). From Equation (10), R_2 is found to be 2.5 kilohms. Substitution of appropriate values show that inequality (11) is satisfied. If cross-coupling condensers, C, of about 100 micro-micro-farads are used, the time constant of the cross-coupling circuit connecting to the turning off collector is about 0.1 microsecond and that of the other about 0.2 microsecond. With transistors having an adequate frequency response, such as the CBS 2N440, the circuit may be operated to count pulses up to a one megacycle pulse rate with pulses of reasonable amplitude. The circuit is shown in *Fig. 10*, including a diode circuit for applying pulses alternately to each collector to cause the flip-flop to change state at each pulse.

The flip-flop may be operated from a single battery by developing a reverse bias through a common emitter resistor as shown in *Fig. 11*. The emitter resistor should be small compared to the collector load resistor in order not to reduce the available output voltage too much. The emitter resistor should be bypassed as shown to aid faster switching. In the relationships (*9*) to (*12*), the collector voltage is effectively re-



(TRANSISTOR SWITCH CIRCUITS)

Fig. 10—Flip-Flop circuit derived in illustrative example

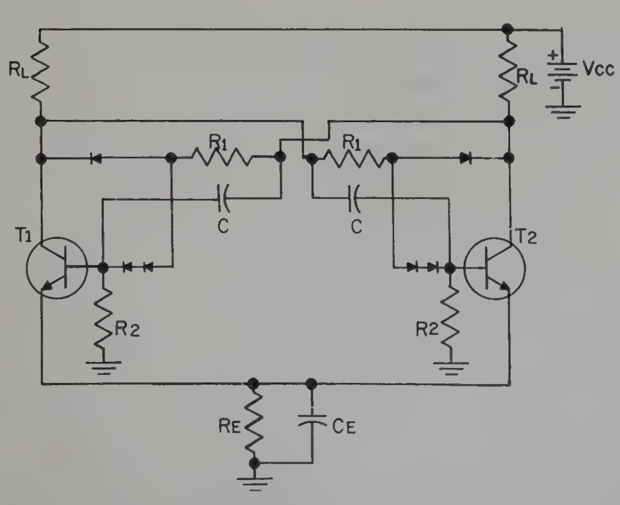


Fig. 11—Single battery operation of Flip-Flop

duced by the bias developed across R_E, and V_{BB} is now this bias voltage. These relationships hold as a first approximation if R_E is small.

Blocking Oscillator

The blocking oscillator is one of the more frequently used transistor switching circuits. It has the advantage of relatively simple circuitry, employing only one transistor and producing a pulse having a very

fast rise time, faster than that produced by a one-shot multivibrator with transistors having the same frequency response. The circuit may be triggered to produce a pulse or may be made free-running.

There are some precautions to be observed in designing blocking oscillators to prevent destruction of transistors. It is possible to produce pulses of the order of amperes in blocking oscillators utilizing low-power, high-frequency transistors. It is very easy, therefore, to destroy a transistor in a blocking oscillator, and important to recognize the factors contributing to excessive currents. It is difficult to give a precise value

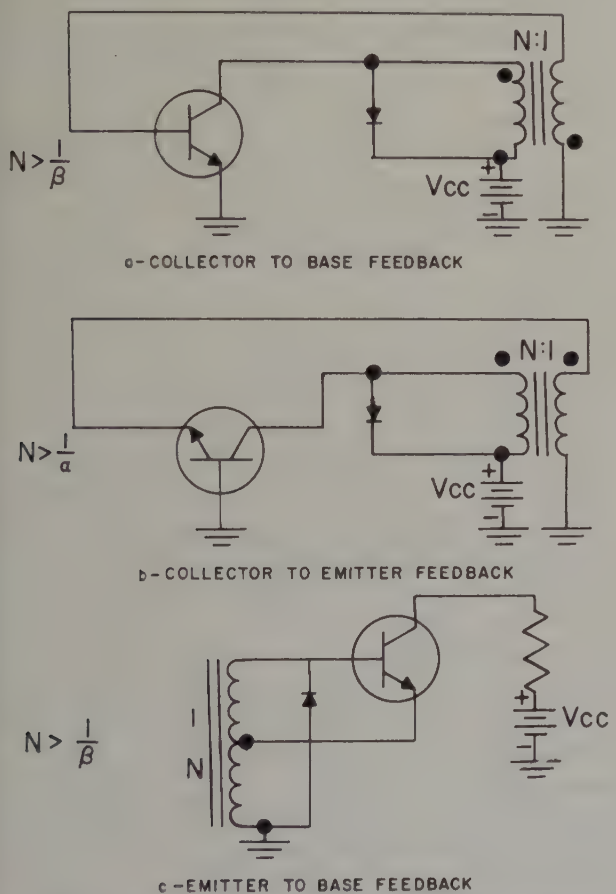


Fig. 12—Some basic blocking oscillator circuits

of what constitutes an excessive collector current in a transistor, for this would be dependent upon the conditions of operation, such as pulse width, the duty cycle, and the thermal resistance and thermal time constant of the transistor. For example, a blocking oscillator, triggered at a 1 *kc* rate and producing a one microsecond pulse, might operate safely with a peak collector current of half an ampere. On the other hand, a blocking oscillator, producing a 500 microsecond pulse at a 50% duty cycle, might be quickly destroyed with a half ampere peak collector current. It is safe to assume that low-power, high-frequency transistors have a high thermal resistance and a low thermal time constant.

Figure 12 shows the basic circuits of several blocking oscillators with the requirements on transformer turns ratios indicated. The diodes are for limiting the inductive kickback voltage which appears when the transistor is cut off at the end of the pulse. The circuit of *Fig. 12a* is commonly used, and the details of its operation will be considered here. The blocking oscillator of *Fig. 12c* is similar to that of *Fig. 12a*.

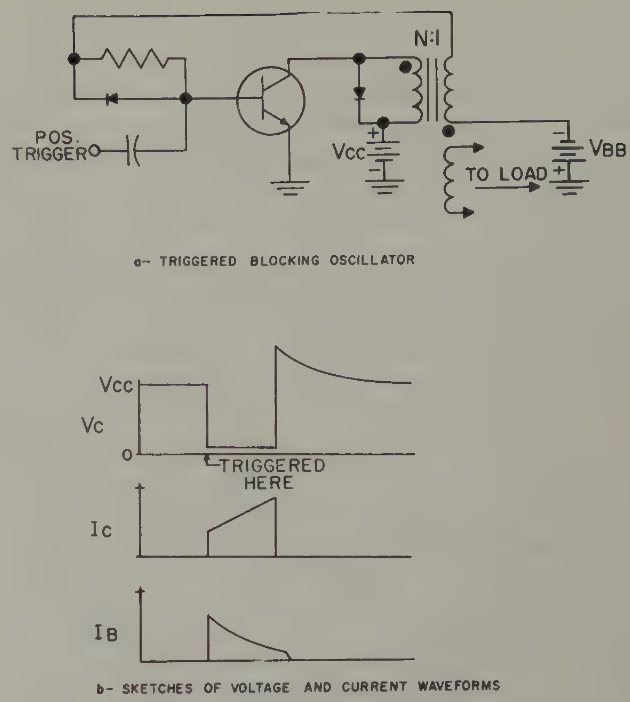


Fig. 13—Triggered blocking oscillator and wave forms

Figure 13 shows a triggered blocking oscillator with its voltage and current waveforms. The base is slightly reverse biased by V_{BB}. The diode in the base circuit reduces the loading on the trigger source. After the circuit is triggered, the diode conducts. When the circuit is triggered, the collector voltage swings negative, and a positive voltage is applied through transformer action to the base, driving the transistor further on. The transistor is quickly driven to the saturated condition. The collector current increases during the pulse interval, and the base current decreases. When the collector current becomes greater than βI_B, the transistor can no longer be held in saturation. The collector voltage then rises, driving the base negative, and the transistor is switched off. The diode across the primary of the transformer conducts, limiting the transformer inductive kickback voltage which would otherwise rise to a value high enough to break down the collector junction. The diode also serves to prevent ringing of the transformer. The circuit may be made free-running by applying a slight positive bias to the base. If this were done, the free-running period would be determined by the recovery time after turn-off, *i.e.*, the free-running period would be dependent on the diode in the collector circuit and the transformer constants. Another means of obtaining free-running operation would be to place a parallel combination of a condenser and resistor in a

series with the emitter and apply a positive bias to the base. Here the free-running period would be governed by the R-C circuit in the emitter, provided that the collector circuit recovers first. There are many possible variations of blocking oscillator operation, and methods employed in vacuum tube circuitry can generally be duplicated with transistors.

A simplified equivalent circuit with the transistor saturated is shown in *Fig. 14*. The bias applied to the base is assumed negligibly small, as are leakage inductances in the transformer. The inductance of the primary is represented by L. The resistance R is the load resistance referred to the primary. The resistance r_1 represents the primary d-c resistance (assumed much smaller than R) plus the resistance of the collector when the transistor is saturated. Resistance r_2 represents the sum of the saturated emitter resistance and any external emitter resistance. When the transformer resistance is negligibly small and there is no external emitter resistance, r_1 and r_2 together make up the saturation resistance of the transistor, a very low value, typically of the order of 3 or 4 ohms for the CBS 2N439 and 2N440. The base resistance r_b represents the saturated base resistance (much smaller than the active region low frequency base resistance, typically of the order of 100 ohms) plus any external resistance in the base circuit. An ideal transformer provides an inverted connection between collector and base circuits. The approximations of *Fig. 14* are valuable in determining roughly the magnitude of the collector current at the end of the pulse, and the duration of the pulse. The resulting expressions show the effects of the transformer turns ratio and circuit parameters on the maximum collector current and indicate how excessive currents may be avoided.

In the simplified calculations based on *Fig. 14*, several assumptions will be made. It will be assumed that the turn-on time of the transistor is very short compared to the pulse duration. It is also assumed that the load, R, is much greater than r_1 and r_2, so that it may be neglected. A further assumption is that r_b is much greater than r_1 and r_2. The purpose of these assumptions is to make the resulting expressions simple enough to reveal the more important characteristics of the circuit.

With these assumptions, the following expressions are obtained for

I_C and I_B:

$$I_C \approx \frac{V_{CC}}{r_s}\left[1-\left(1-\frac{r_s}{N^2 r_b}\right)e^{\frac{-r_s}{R_L}t}\right],\quad 0 < t < T_d \quad (13)$$

$$I_B \approx \frac{-V_{CC}\, r_2}{r_b\, r_s}\left[1-\left(1+\frac{r_s}{N\, r_2}\right)e^{\frac{-r_s}{R_L}t}\right],\quad 0 < t < T_d \quad (14)$$

In equations (13) and (14), T_d is the duration of the pulse, and r_s is the sum of r_1 and r_2.

The pulse ends when I_C becomes larger than βI_B. By equating I_C to βI_B, the pulse duration is given by

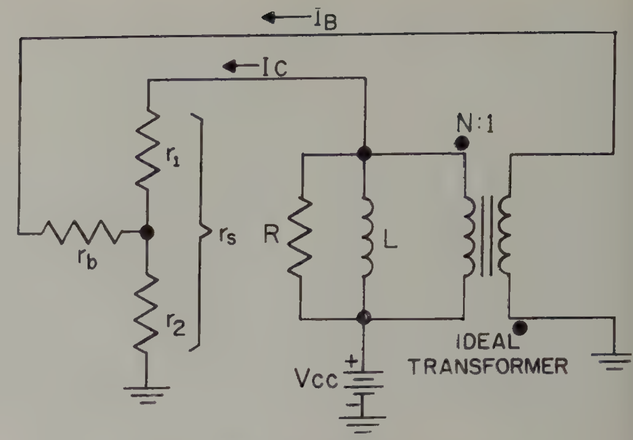


Fig. 14—Approximate equivalent circuit of blocking oscillator for transistor in saturation

$$T_d \approx \frac{L}{r_s}\ln\frac{1-\frac{r_s}{N^2 r_b}+\beta\left[1+\frac{r_s}{N\, r_2}\right]\frac{r_2}{r_b}}{1+\frac{\beta r_2}{r_L}} \quad (15a)$$

If $\beta r_2 \gg r_b$,

$$T_d \approx \frac{L}{r_s}\ln\left(1+\frac{r_s}{N r_2}\right),\ \beta r_2 \gg r_b \quad (15b)$$

From Equation (15b) it is seen that, for transistors having a large current gain, the pulse duration is relatively independent of r_b and is largely determined by L, r_s, and the turns ratio N. Equations (15) show that for a given r_s and a given L, the pulse width may be controlled by the transformer turns ratio. A large value of N (stepdown between collector and base) decreases the pulse width, whereas a small value of N increases the pulse width. Thus is is apparent, since the collector current increases during the pulse, that, as the turns ratio is decreased, the peak collector current will be increased. This is made clearer by substituting (15a) into (13) to obtain the expression for the maximum collector current at the end of the pulse:

$$I_C\,\text{max.} \approx \frac{V_{CC}}{Nr_2}\;\frac{\left(1+\frac{r_2}{N r_b}\right)\frac{\beta r_2}{r_b}}{1-\frac{r_s}{N^2 r_b}+\frac{\beta r_2}{r_b}\left(1+\frac{r_s}{N r_2}\right)} \quad (16a)$$

If the current gain is large,

$$I_C\,\text{max.} \approx \frac{V_{CC}}{Nr_2 + r_s},\ \text{for}\ \beta r_2 \gg r_b\ \text{and}\ N r_b \gg r_2 \quad (16b)$$

From equations (16) it is seen the I_C max is directly proportional to V_{CC} and is increased by decreasing the transformer turns ratio. The inductance does not enter the expression for the maximum collector current. The peak collector current may be effectively reduced by reducing the supply voltage, increasing the turns ratio, and increasing r_1 or r_2 or both. The peak current may also be reduced by increasing the base resistance, although I_C max is less strongly a

function of base resistance, particularly if the gain of the transistor is high.

Another point to be considered is the inductive voltage rise at the termination of the pulse. The collector voltage at the end of the pulse is $V_{CC} + I_C$ max r_d, where r_d is the forward resistance of the diode plus any resistance placed in series with the diode. This voltage may be quite large. For example, if I_C max were 200 milliamperes and r_d were 300 ohms V_C max would be, for a V_{CC} of 6 volts, 66 volts, provided that the collector junction did not break down at this voltage. If the collector junction breaks down, the dissipation in the transistor may be very high for the duration of the breakdown.

As an example, suppose a blocking oscillator producing a pulse of about 5 microseconds duration is desired, and the peak collector current is to be held to 150 milliamperes for a 6-volt supply. The values of r_1, r_2 and r_b for the transistor are not accurately known but are estimated as roughly 2, 2, and 100 ohms respectively, and are subject to some variation from transistor to transistor. To work with known values, one might insert, for example, 10 ohms in series with the emitter lead, thus making r_2 12 ohms and r_s $(r_1 + r_2)$ about 14 ohms. If the current gain of the transistor is high, the peak current is relatively insensitive to r_b. Assuming a large current gain, (16b) indicates a turns ratio of 2.16 would be satisfactory. Assuming a β of 40, and inserting values in (16a), gives an I_C max of 140 milliamperes.

Equation (15b), appropriate for transistors having a very high current gain, gives 162 microhenries as the primary inductance. Equation (15a) gives a primary inductance of 188 microhenries, assuming as before a transistor with a current gain of 40 and a base resistance of 100 ohms. For rough calculations equations (15b) and (16b) may be used as demonstrated.

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Transistor Characterization at VHF‡

R. P. ABRAHAM* and R. J. KIRKPATRICK*

PART 2

This article describes a technique for the characterization of transistors in the common emitter configuration at very high frequencies (30-300 *mc*). The characterization consists of four measurements and subsequent calculations which yield the four complex hybrid parameters; the hybrid parameters may then be used to find the validity as well as the element values of any equivalent circuit. The measurements which are made are (1) insertion voltage gain, (2) input impedance with a load of 50 ohms, (3) h_{22}, and (4) y_{22}. In the VHF region transmission line techniques become necessary; thus, coaxial jigs have been designed to provide the transition between the transistor and the coaxial line as well as to accommodate the bias circuitry. These jigs in conjunction with a Rhode-Schwartz Diagraph provide the necessary measurement equipment. The calculations needed to transform the measured data to the hybrid parameters are programmed on a digital computer. These calculations also take account of the small imperfections in the jigs. Typical data on the diffused base type of transistor is presented. These data are shown to be in good agreement with the calculated performance of a tee equivalent circuit.

VI. CALCULATION OF THE HYBRID PARAMETERS

The reduction of the measured data (see *Fig. 11*) consists of three steps; first, the effects of shunt and series parasitics are removed; second, the imperfect terminations are taken into account; and third, the effect of common impedances (emitter lead inductance) is eliminated.

First Step

As shown in *Fig. 5* the shunt capacity has been assumed to precede the series inductance in the evaluation of the jig parasitics because of physical considerations and ease of calculation. For immittance measurements the shunt admittance is subtracted and then the effect of lead inductance is eliminated;

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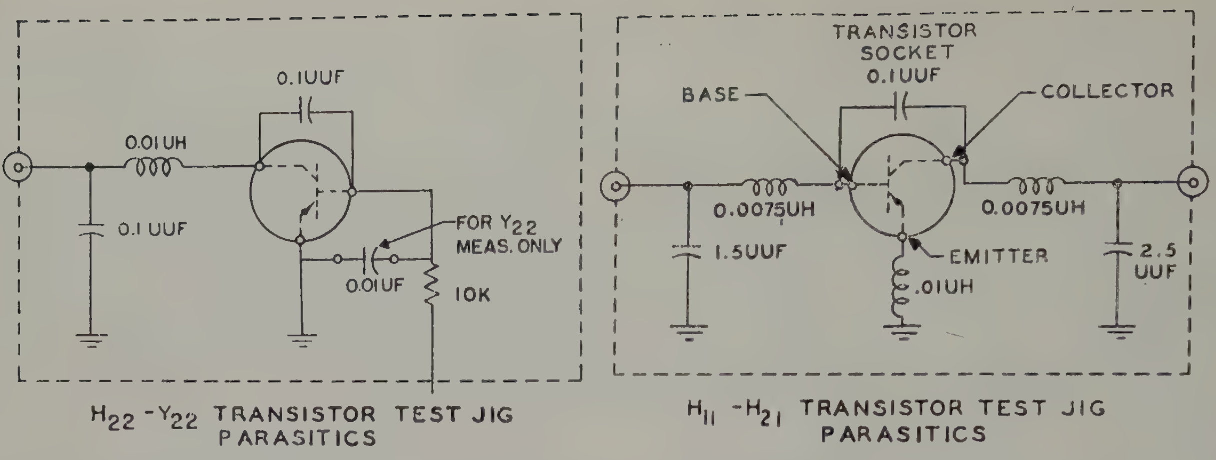


Fig. 5—Schematic diagram for jig parasitics.

for the insertion voltage gain measurement these parasitics must be accounted for in order to calculate the current flowing into and out of the transistor. In all cases these corrections are small enough to keep the accuracy intact.

Second Step

After this first step the corrected data still contain the effects of improper termination as well as the inaccuracies produced by the presence of common impedances. From this data the hybrid parameters for the transistor *including* the effects of the common impedance (emitter lead inductance) are calculated taking the improper terminations into account. (These hybrid parameters are denoted with a capital H; the transistor parameters are denoted by a lower case h.)

The output admittance can be shown to be (see *Fig. 11C*)

$$Y_{10} = H_{22} - \frac{H_{12}H_{21}}{H_{11} + Z_{Lo}} \qquad (6)$$

where Z_{Lo} is the impedance from base to ground (instead of the ideal open circuit). Equation (6) may be written as

$$Y_{10} = H_{22}\left[1 - \frac{H_{12}H_{21}}{H_{22}\,(H_{11} + Z_{Lo})}\right] \qquad (7)$$

The second term on the right hand side of (7) represents the termination error; this error may be evaluated by using the hybrid parameters of the equivalent circuit. (See Section V.) If the maximum value of $|H_{12}|$ is 0.1 and $|H_{21}|$ may be approximated by (see Eq. (3))‡

$$|H_{21}| \approx \frac{f_{ae}}{f} \qquad (8)$$

at frequencies $f \gg f_{ae}\,(1 - a_o)$, then

$$|H_{21}\,H_{12}| < \frac{f_{ae}}{10f} \qquad (9)$$

‡It is assumed that the difference between the H's and h's is negligible for the purpose of evaluating the termination error.

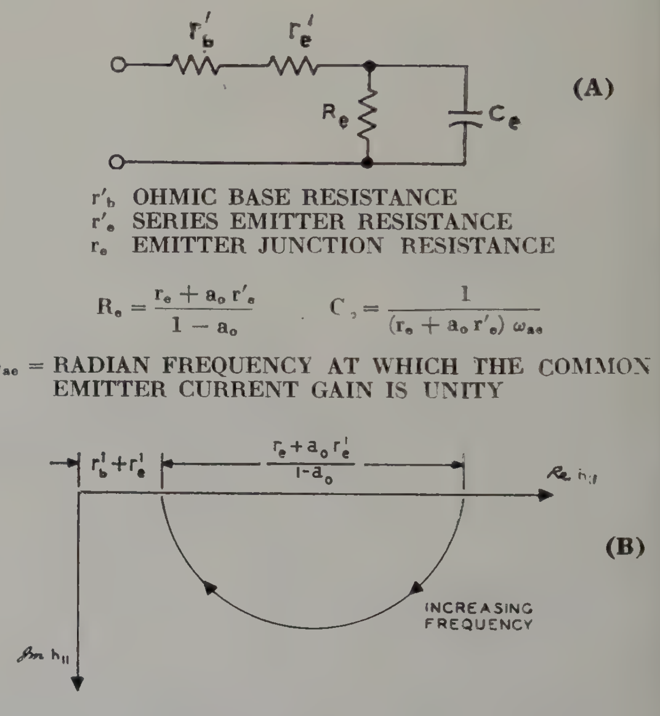


Fig. 7—Equivalent circuit for short circuit input impedance.

Using the same kind of approximation $|H_{22}|$ may be written as

$$|H_{22}| = \left|\frac{2\pi f\,(C_c + C_f)}{1 - a}\right| \approx 2\pi\,(C_c + C_f)\,f_{ae} \qquad (10)$$

Now, in evaluating the magnitude of the error term in expression (7), H_{11} will be ignored (this assumption increases the size of the error). The error is

$$\left|\frac{H_{12}H_{21}}{H_{22}\,(H_{11} + Z_{Lo})}\right| < \frac{1}{20\pi f\,(C_c + C_f)\,Z_{Lo}} \qquad (11)$$

and if Z_{Lo} can be represented by a capacity, C_{Lo}, the magnitude of the error may be expressed as

$$\text{Error} < \frac{C_{Lo}}{10\,(C_c + C_f)} \qquad (12)$$

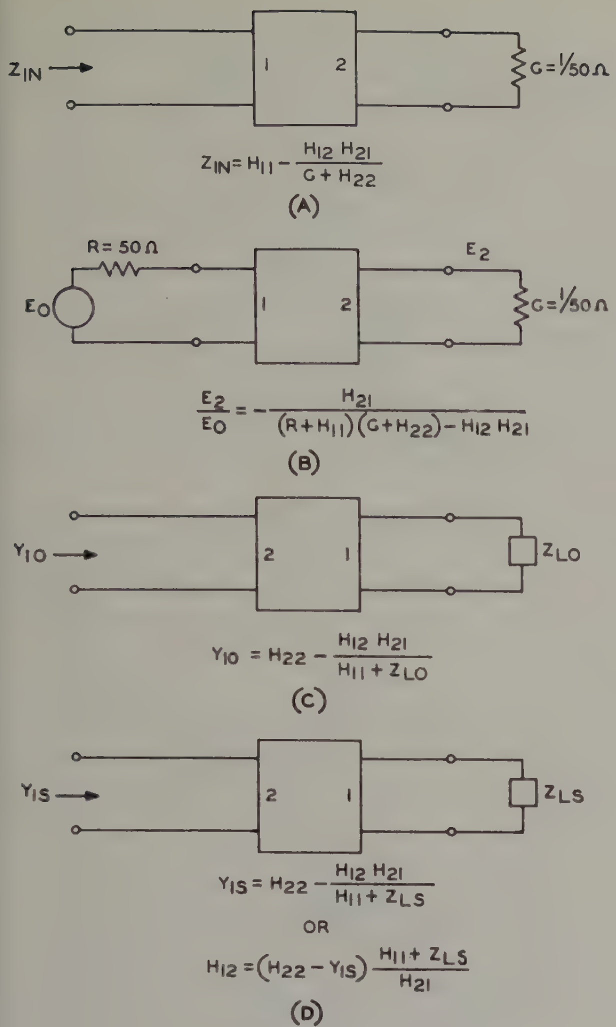


Fig. 11—Actual Measurements.

The jig evaluation has shown that C_{Lo} is at most 0.1 μμf; therefore, if $C_c + C_f = 1$ μμf the maximum error would be 1%. The termination error for the H_{22} measurement is negligible in most cases.

The determination of H_{12} is made by using the Y_{1S} measurement in conjunction with the other hybrid parameters. If Z_{LS} is the impedance between base and ground (instead of a perfect short circuit), then the output admittance is (see *Fig. 11D*)

$$Y_{1S} = H_{22} - \frac{H_{12} H_{21}}{H_{11} + Z_{LS}} \tag{13}$$

Rearranging yields

$$H_{12} = (H_{22} - Y_{1S}) \frac{(H_{11} + Z_{LS})}{H_{21}} \tag{14}$$

The jig evaluation showed that Z_{LS} is less than 2 ohms at all frequencies of interest and the magnitude of $|H_{11}| > r'_b$ (see *Fig. 7A*); therefore, this error will almost always be negligible.

The input impedance of a transistor (including the effect of emitter lead inductance) with a load of 50 ohms $(1/G)$ is, in terms of the hybrid parameters (see *Fig. 11A*),

$$Z_{in} = H_{11} - \frac{H_{12} H_{21}}{G + H_{22}} \tag{15}$$

or

$$H_{11} = Z_{in} + \frac{H_{12} H_{21}}{G + H_{22}} \tag{16}$$

The second term on the right hand side of (16) is the impedance error caused by the improper termination; the percentage error may be as high as 15%.

The insertion voltage ratio can be shown to be (see *Fig. 11B*)

$$\frac{E_2}{E_o} = - \frac{H_{21}}{(R+H_{11})\,(G+H_{22}) - H_{12} H_{21}} \tag{17}$$

or

$$-H_{21} = \frac{E_2}{E_o} \frac{(R+H_{11})\,(G+H_{22})}{\left(1 - \frac{E_2}{E_o} H_{12}\right)} \tag{18}$$

The termination error due to the appearance of the term involving H_{12} may be as large as 15%.

H_{22} is determined directly from Y_{10} since the termination error is negligible. To determine the remaining hybrid parameters which represent the transistor and the series emitter lead inductance, equations (14), (16), and (18) must be solved simultaneously in order to take account of the sizeable termination errors.

Third Step

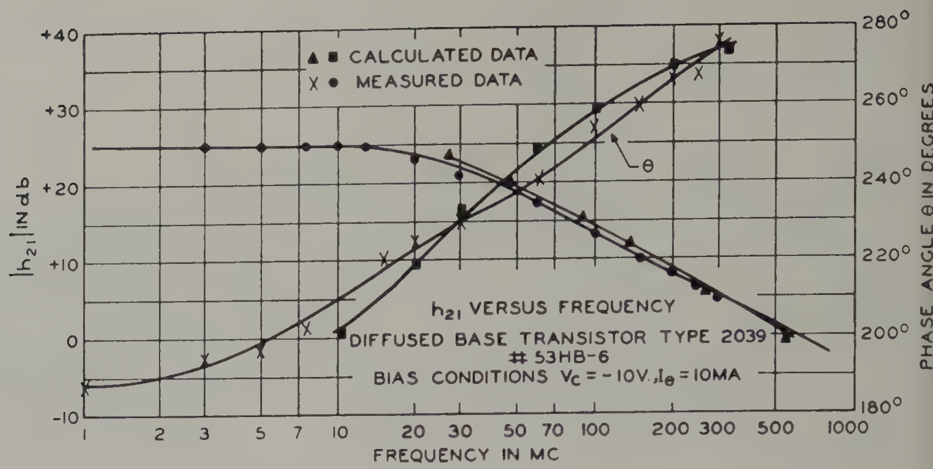
The third step is to extract the transistor hybrid parameters (h) from the hybrid parameters (H) representing the transistor plus any common impedances. The bridging capacity is neglected since its maximum value (0.1 μμf) is small compared to the collecter to base capacity (C_f) of the transistor (header). The effect of emitter lead inductance can be removed by solving another set of equations which express the h parameters in terms of the H parameters.

All of the calculations necessary to transform the measured data to the device hybrid parameters are programmed for a digital computer. Appendix B gives a complete list of the necessary formulas.

VII. COMPARISON OF DATA WITH THEORY

Figures 12 through *15* compare the measured hybrid parameters to the hybrid parameters calculated from the assumed equivalent circuit of a typical diffused base transistor. The data below 30 *mc* were obtained using conventional techniques. These comparisons show good agreement; hence the element values of the tee equivalent circuit can be determined. For the particular transistor measured, the element values are as follows:

Fig. 13—h_{21} diffused base.



h_{11} (see *Fig. 12*)

$r'_b = 50$ ohms

$r'_e = 4$ ohms

h_{21} (see *Fig. 13*)

$a_o = 0.95$

$f_a = 900$ *mc*

$m = 0.5$

h_{22} (see *Fig. 14*)

$C_c = 0.3\ \mu\mu f$

r'_c not estimated

h_{12} (see *Fig. 15*)

$C_f = 0.9\ \mu\mu f$

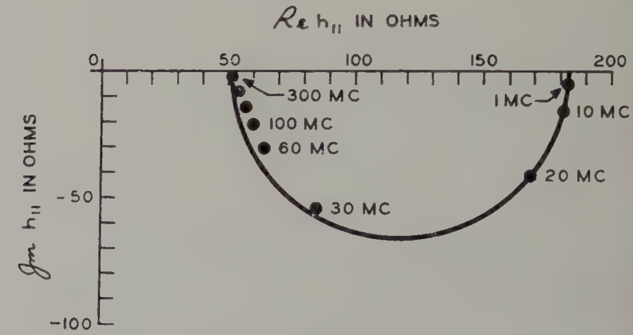


Fig. 12—h_{11} diffused base.

There are several methods of showing the self-consistency of the final data. As an example, if

$$\frac{f_a\,(1-a_o)}{1+a_o m} < f < \frac{f_a}{m},$$

then h_{22} may be approximated by

$$h_{22} \approx (C_c+C_f)\ \omega_{ae} + j\omega\left[C_s + \frac{(C_c+C_f)}{1+a_o m}\right]. \qquad (19)$$

Now, if ω_{ae} and m are determined from the h_{21} data and C_s, the stray capacity from collector to ground, can be evaluated by other means, $C_c + C_f$ can be calculated in two ways by using the real and imaginary parts of expression (20). The diffused base transistor for which the data is presented was mechanically mounted such that $C_s = 0.2\ \mu\mu f$; C_f was found to be $0.9\ \mu\mu f$. From *Fig. 14* the asymptotic values for R_p and C_p are 230 ohms and 1 $\mu\mu f$, respectively. The h_{21} data (*Fig. 13*) was used to estimate ω_{ae} and m; these values are $\omega_{ae} = 2\pi \times 600 \times 10^6$ radians per second, $m = 0.5$. Using the real part, $C_f + C_c$ should be 1.15 $\mu\mu f$; the calculation using the imaginary part yields 1.2 $\mu\mu f$ for $C_f + C_c$; hence, the agreement is excellent.

VIII. CONCLUSION AND ACKNOWLEDGMENTS

This memorandum has described techniques and equipment which allows the measurement of the *complex* hybrid parameters of a transistor in the common emitter configuration in the 30-300 *mc* range. It has also been shown that the diffused base type of transistor may be characterized accurately at these frequencies in terms of a tee equivalent circuit.

The authors wish to acknowledge the assistance of Miss Phyllis D'Alessandro with regard to digital computer programming, and the assistance of F. Novorski and R. Panek in the actual measurements as well as in the correlation of data.

APPENDIX B

This appendix lists the sequence of computations necessary for the transformation of raw data to the hybrid parameters for the transistor in the common emitter configuration.

Removal of Shunt and Series Immittance

1. h_{22} (See *Fig. 11C*)

The shunt capacity is neglected since it is less than 0.1 $\mu\mu f$ and the common inductance is lumped with the series inductance (this is permissible since very little current is flowing in the base circuit), hence,

$$h_{22} = \frac{Y_{10}}{1 - j\,\omega\,L_o\,Y_{10}} \qquad (30)$$

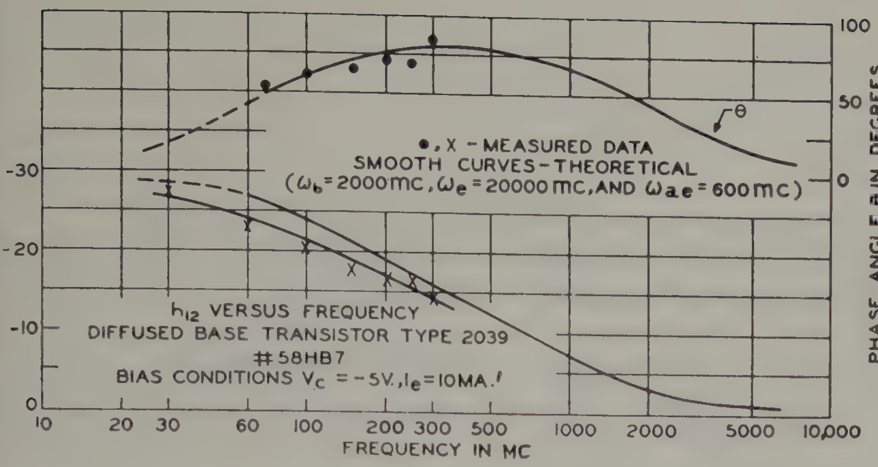


Fig. 15—h_{12} diffused base.

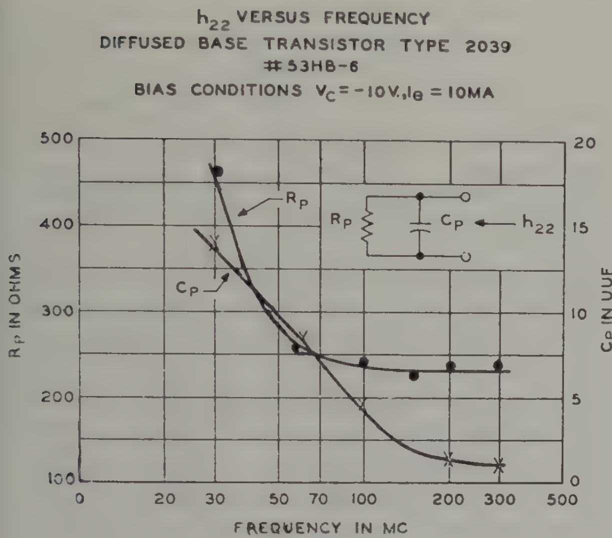


Fig. 14—h_{22} diffused base.

where L_o is the total series and common inductance and Y_{10} is the raw measurement.

2. y_{22} (See *Fig. 11D*)

Again, the shunt capacity is neglected and the inductance may be taken as being in series, thus

$$y_{22} = \frac{Y_{1S}}{1 - j\,\omega\,L_o\,Y_{1S}} \tag{31}$$

were Y_{1S} is the raw measurement.

3. h_{11} (See *Fig. 11A*)

The shunt admittance is subtracted and the series inductance removed.

Thus

$$Z_{in} = \frac{Z'_{in}}{1 - Z'_{in}Y_{ix}} - j\omega L_1 \tag{32}$$

where Z'_{in} is the raw data; Y_{ix} is the shunt admittance; and L_1 is the series inductance. Z_{in} is the input impedance for the transistor terminated with 50 ohms and including the effect of emitter lead inductance.

4. h_{21} (See *Fig. 11B*)

The effect of series and shunt parasitics may be taken into account by lumping them with the generator resistance and load resistance, respectively. The voltage which is actually measured, E'_2, is related to the collector voltage by

$$E_2 = E'_2\,(1 + j\omega L_o\,Y'_L) \tag{33}$$

where L_o is the series inductance in the output circuit and Y'_L is the parallel combination of the load resistance (50 ohms) and the parasitic shunt admittance.

Termination Error

In order to eliminate any termination errors, the following equations must be solved simultaneously

$$H_{11} = Z_{in} + \frac{H_{12}\,H_{21}}{Y_L + H_{22}} \tag{34}$$

$$H_{12} = (H_{22} - Y_{22})\,\frac{H_{11}}{H_{21}} \tag{35}$$

$$-H_{21} = \frac{E_2}{E_o}\,\frac{(Z_G + H_{11})\,(Y_L + H_{22})}{\left(1 - \frac{E_2}{E_o}\,H_{12}\right)} \tag{36}$$

where H_{11}, H_{22}, H_{12}, and H_{21} are the hybrid parameters including the effect of emitter lead inductance; Y_{22} is the short circuit output admittance including the common impedance:

$$Z_G = j\omega L_1 + \frac{1}{Y_{ix} + G} \tag{37}$$

and

$$Y_L = \frac{Y'_L}{1 + j\omega L_o\,Y'_L} \tag{38}$$

The parameters H_{22} and Y_{22} must be calculated since the simple correction of the measured data yields h_{22} and y_{22}. The relations are

$$H_{22} = \frac{h_{22}}{1 + h_{22}Z} \tag{39}$$

and

$$Y_{22} = \frac{H_{22}}{H_{11}}\,Z + y_{22}\left(1 - \frac{Z}{H_{11}}\,[H_{11}H_{22} + H_{12}H_{21} + H_{21} - H_{12} + 1]\right) \tag{40}$$

where Z is the impedance of the emitter lead inductance.

Removal of the Common Impedance

The solution of the simultaneous equations (34), (35), and (36) yield the H parameters (including the emitter lead inductance). The expression relating the H parameters to the h parameters are as follows:

$$h_{22} = \frac{H_{22}}{1 - H_{22}Z} \tag{41}$$

$$h_{12} = \frac{H_{12} - H_{22}Z}{1 - H_{22}Z} \tag{42}$$

$$h_{21} = \frac{H_{21} + H_{22}Z}{1 - H_{22}Z} \tag{43}$$

$$h_{11} = H_{11} - Z - \frac{H_{12}H_{21}}{H_{22}} + \frac{(H_{12} - H_{22}Z)\,(H_{21} + H_{22}Z)}{(1 - H_{22}Z)\,H_{22}} \tag{44}$$

These equation yield the hybrid parameters for the common emitter configuration of the transistor under test.

Intermetallic Semiconductors

HENRY T. MINDEN*

The intermetallic semiconductors indium antimonide, indium arsenide, indium phosphide, gallium arsenide, cadmium telluride, mercuric telluride, and bismuth telluride are discussed. Methods of synthesis, purification and single crystal growth are described. Interesting properties of these compounds are discussed, and some of their applications are listed.

[*Editor's Note: This article originally appeared in the January 1958 issue of "The Sylvania Technologist." As published in this issue of SCP, it contains minor additional material reflecting recent experimental data.*]

SINCE 1948 THE PRODUCTION of transistors and other semiconductor devices has become an important industry in the United States. In fact, these devices have opened up new vistas in electronics engineering, so that hardly a week goes by without the announcement of a new application, and now even more revolutionary semiconductor devices have either been suggested or are under development.

With a few significant exceptions germanium, silicon, and selenium are still the only materials used in semiconductor devices. During the past five years, however, there has been a growing awareness of the fact that these elements may not be the ultimate semiconductors. In fact, a demand has arisen not only for semiconductors with better properties than germanium, silicon, and selenium, but also for a variety of semiconductors having different but useful properties. This demand has led several farsighted laboratories to initiate research and development programs on compound semiconductors. Each of the compound semiconductors has almost a distinct personality, and as a group they present a kaleidoscopic array of properties. The purpose of this paper is to describe the methods of preparation, properties, and applications of some of the more interesting of these compounds.

Summary

Intermetallic semiconductors are usually synthesized by melting together the elements in a sealed, evacuated quartz tube. The starting elements are extensively purified by a variety of processes including distillation and zone refining. The compounds are also zone refined, although the apparatus usually employed must be modified to prevent decomposition. All the techniques used for growing germanium single crystals have been successfully adapted to several of the compound semiconductors.

A set of empirical rules has been derived[1] to predict whether or not a given compound will be a semiconductor. Semiconducting compounds can be arranged in various homologous series; generally in a given series, the more ionic the crystal is, the higher the energy gap and the lower the carrier mobility.[37] Energy gaps in compound semiconductors have values from less than 0.1 ev up to more than 1.5 ev, providing a complete transition from metallic to insulating behavior. Mixed crystals of certain intermetallic semiconductors in varying proportions provide a continuous range of energy gaps.

The carrier mobilities of compound semiconductors are often larger than those of a Group IV element having a similar energy gap. The high electron mobility in many intermetallic semiconductors results from a low effective electron mass. This low effective mass is associated with a low density of quantum states per unit energy in the conduction band. Interesting physical effects associated with the low effective mass and density of states have been observed, and the results have yielded information about the energy band structure of solids.

Table I lists some of the important properties of several intermetallic semiconductors of present or potential interest.

Impurities play a role in compound semiconductors similar to that in elemental semiconductors. In compounds the variety of interesting impurities is somewhat greater, and more complex effects are often observed. Defect structures associated with deviations from stoichiometry can also act as donors or acceptors. *P-N* junctions have been produced in some of the intermetallic compounds, and some unusual surface effects have also been observed.

Diodes, transistors and solar batteries have been made from compound semiconductors, and infrared photocells are made exclusively from them. A wide variety of devices are based on the Hall effect and magnetoresistive effect of compounds having high carrier mobility; many of these devices are in production.

Indium antimonide, InSb, is perhaps the simplest compound to prepare and the most rewarding to investigate. It is readily prepared in pure single crystal form, and its high electron mobility permits the observation of many of the effects mentioned above. Indium arsenide, InAs, is similar to InSb, but is more difficult to prepare, because of the volatility of arsenic

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over the compound. Indium phosphide, InP, and gallium arsenide, GaAs, are also difficult to prepare because of the volatility of phosphorous and arsenic. They have a higher energy gap than that of silicon and their carrier mobilities are comparable with that of germanium. GaAs is somewhat more manageable than InP because of its lower equilibrium arsenic vapor pressure at the melting point; it is also regarded as a potential replacement for Si and Ge in some diode and transistor applications. GaAs or cadmium telluride, CdTe, may possibly supplant silicon for solar batteries. Mercuric telluride, HgTe, is an interesting semimetal with properties and applications similar to those of InSb. Bismuth telluride, Bi_2Te_3, is an unusual semiconductor having a very low thermal conductivity. This property has led to its application as a thermoelectric generator material and in thermoelectric refrigeration.

TABLE I

Properties of Some Semiconductors

Compound	Melting Point in °C	Energy Gap[a] in ev	Mobilities in cm^2/volt-sec	
			Electrons	Holes
Si	1420	1.1	1200	500
Ge	936	0.68	3800	1900
Sn (gray)	—	0.08	2000	1000
AlP	—	3.0	—	—
AlAs	1600	2.2	1200	200
AlSb	1060	1.6	200	460
GaP	—	2.4	—	—
GaAs	1240	1.35	8000	350
GaSb	720	0.7	4000	850
InP	1070	1.25	3400	650
InAs	940	0.35	50000	200
InSb	535	0.18	—	1250
CdSe	1350	1.74	—	—
CdTe	1045	1.5	300	—
HgSe	~800	0.16	~15000	—
HgTe	650	0.02	15000	—
PbS	1100	0.34	580	—
PbSe	1065	0.22	—	—
PbTe	904	0.27	—	—
Mg_2Si	1102	0.77[b]	—	—
Mg_2Ge	1150	0.80	—	—
Mg_2Sn	770	0.33 (5°K)	—	—
Bi_2Te_3	585	0.15	800	400
Bi_2Se_3	706	0.35	600	—
Sb_2Te_3	620	0.3	—	270

[a] From optical data at 300°K
[b] From thermal data

Indium Antimonide

Preparation. Indium antimonide,[2] InSb, melts at 535°C and is readily prepared from a melt of the elements. For semiconductor purposes the elements are placed in a boat, and a molten zone is passed through the mixture. The stoichiometric compound freezes out at the edge of the zone, and so far there is no evidence of a solid solubility of an excess of either of the elements. The elements and the compound are purified by zone refining, but zinc and tellurium are troublesome impurities that must be removed from the indium.[3] This is done prior to the synthesis of the compound by zone refining the metal and by the electrodeposition of indium from a fluoroborate solution. Single crystals of InSb are readily pulled from the melt by the Czochralski technique. Samples have been prepared with an uncompensated extrinsic carrier concentration as low as $10^{14}cm^{-3}$, a purity comparable with that achieved in Ge and Si.

Properties. Indium antimonide is a so-called III-V compound semiconductor because indium is in Group III of the periodic table and antimony is in Group V. The compound crystallizes in the zincblende structure. If one were to ignore the identity of the atoms, this structure would be like the diamond lattice characteristic of germanium and silicon. The difference is that whereas in germanium each Ge atom is surrounded by four others, in indium antimonide each In atom is surrounded by four Sb atoms and vice versa. Stated in other terms, there are two Ge atoms per unit cell in the one structure, while there is one InSb "molecule" per unit cell in the other. InSb is isoelectronic with gray tin.

Some of the semiconducting properties of the III-V zincblende type of compound can be understood by analogy with germanium. Zinc, cadmium and mercury (Group II elements) substitute for indium as acceptor impurities, whereas sulfur, selenium and tellurium (Group VI elements) substitute for antimony as donor impurities. These impurities act in the same way for all III-V compounds with the zincblende lattice. A deficiency of antimony in the InSb lattice can be produced by outdiffusion under vacuum. It has been shown experimentally that antimony-deficient InSb is a p-type semiconductor. Consideration of the zincblende lattice shows that this behavior is to be expected from antimony vacancies rather than interstitial indium.

InSb has an energy gap of 0.18 ev at room temperature. It has the astonishingly high electron mobility of 75,000 cm^2/volt-sec, while its hole mobility is only 1250 cm^2/volt-sec. The high electron mobility results primarily from a low effective electron mass.

The low effective mass is a fundamental property of the InSb band structure, and it reflects a low density of quantum states per unit energy in the conduction band. Even at moderate donor concentrations, the free electron concentration is high enough to fill completely the relatively few states available at the bottom of the conduction band, forming a so-called degenerate electron gas. Because optical transitions cannot take place from the valence band to filled states in the conduction band, the absorption edge in InSb is displaced to shorter wavelengths with increasing donor concentration,[4] as shown in Fig. 1. As the bottom of the con-

duction band becomes filled by increased doping, a smooth transition occurs from semiconducting to metallic behavior. A study of this transition has revealed the structure of the conduction band beyond the region usually considered; in the latter the energy is simply proportional to the square of the crystal momentum.[5] As the Fermi level is raised into the conduction band, the effective mass of the electrons in the vicinity of the Fermi level has been observed to increase. With heavy doping this increase was about 15%.

Another interesting effect of the low effective mass of the conduction electron is a high cyclotron resonance frequency.[6] When the current carriers in a solid with a simple type of band structure are subjected to a magnetic field H they tend to move in circular paths at an angular frequency $\omega = eH/m^*c$, where m^* is the effective mass. These circular motions are interrupted by collisions 10^{11} times a second.[6] At easily obtainable magnetic fields, say about 20,000 gauss, ω for electrons in InSb is large enough for them to complete an appreciable fraction of a cycle between collisions. The resonance absorption of radiation at angular frequency ω can be observed, and accurate determination of the effective mass has been made in this manner. At ultra-high magnetic fields of 100,000 gauss, deviations from the simple cyclotron resonance frequency have been observed;[7] the increase in the apparent effective electron mass has tended to confirm the observations described above on highly doped InSb.

The lifetime, τ, of injected carriers in InSb is very short, about one microsecond. The evidence is that recombination of excess electrons and holes takes place directly rather than at recombination centers. Unlike the corresponding situation in germanium and silicon, very little increase in lifetime is obtained by purifying InSb. Nonetheless, because of the high electron mobility (and hence diffusion constant D) the electron diffusion length, $L = \sqrt{D\tau}$, is high.

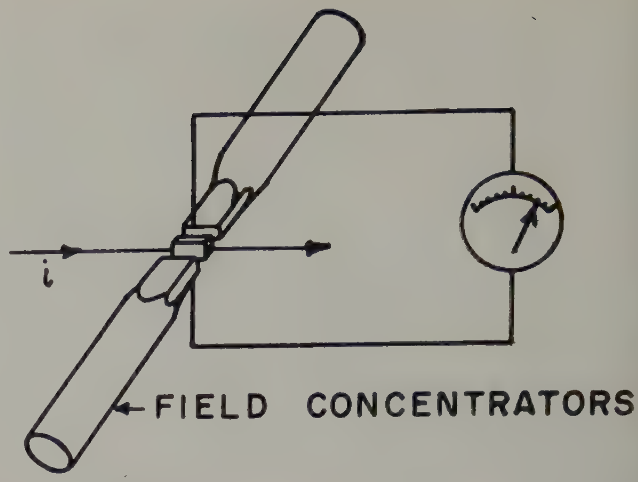

Fig. 4—Hall effect compass with gap enlarged for clarity.

As a result of the high diffusion length, many interesting phenomena associated with carrier injection have been observed in InSb. Two of these are the photoelectromagnetic (PEM) effect and the photoconductive effect. The photoelectromagnetic effect can be described with the aid of Fig. 2. Light falls on the x-z surface of the sample where excess hole-electron pairs are created. These excess carriers diffuse in the y direction, but their paths are deflected by the magnetic field in the z direction. The net result is a current in the x direction, the magnitude of which depends on the diffusion length among other things. Both the photoconductive effect and the photoelectromagnetic (PEM) effect have been extensively studied.[8] The rate of decay of the photoconductivity is too fast for accurate measurement of lifetimes, but the ratio of the photoconductive effect to the PEM effect does give a measure of the lifetime and the surface recombination velocity.[9]

Grown p-n junctions have been made by doping a melt with an acceptor impurity such as zinc or cadmium, and dipping in an n-type crystal in the conven-

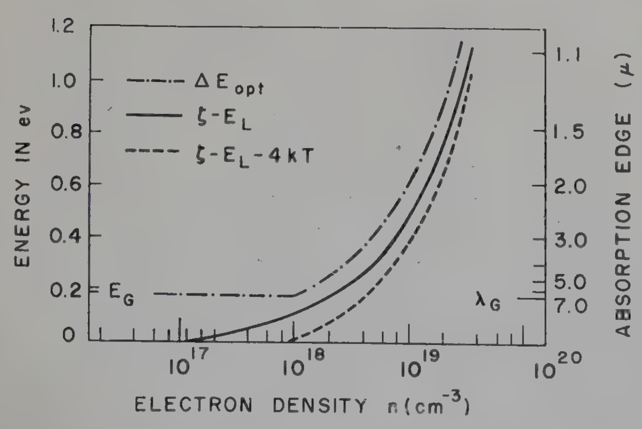

Fig. 1—Change in optical absorption edge and apparent energy gap in InSb owing to degeneracy in the conduction band. (Ref. 2)

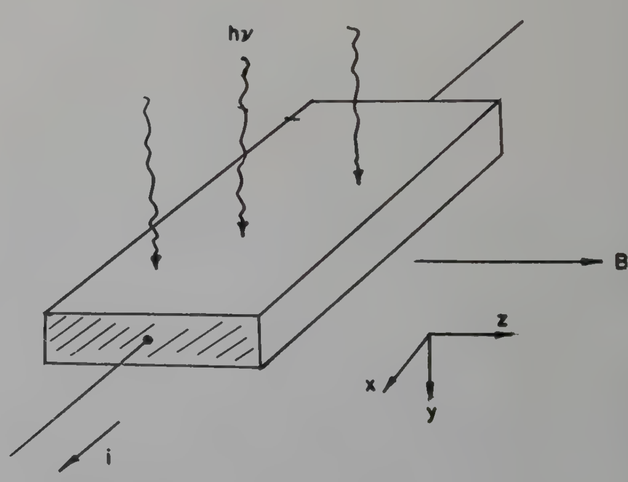

Fig. 2—The photoelectromagnetic effect.

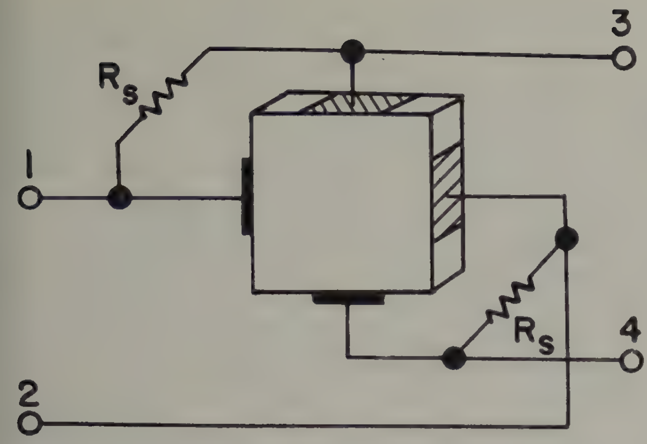

Fig. 5—Connections for a Hall effect gyrator. In the presence of a normal magnetic field the attenuation is nonreciprocal.

tional manner.[10] Rate-grown junctions have also been made. Broad-area surface junctions have been produced by out-diffusing antimony in vacuum from the surface of an n-type crystal, producing a p-n junction just inside the surface.

Applications. One of the consequences of the high carrier mobility in InSb is the fact that large Hall voltages can be produced in pure material by relatively small magnetic fields.[11] Fig. 3 is a graph of the Hall voltage as a function of magnetic field strength. Gaussmeters using InSb have been produced.[12] If an InSb sample is placed between two mu-metal rods as shown in Fig. 4, the earth's magnetic field can be concentrated across the sample. The magnetic field across the sample, and hence the Hall voltage, depends on the orientation of the rods with respect to the earth's field. An alternating input current can be used, and the Hall voltage output can be amplified and suitably adjusted to drive, say, the servomotors of an autopilot. This eliminates the costly gyro sensing mechanism currently in use.

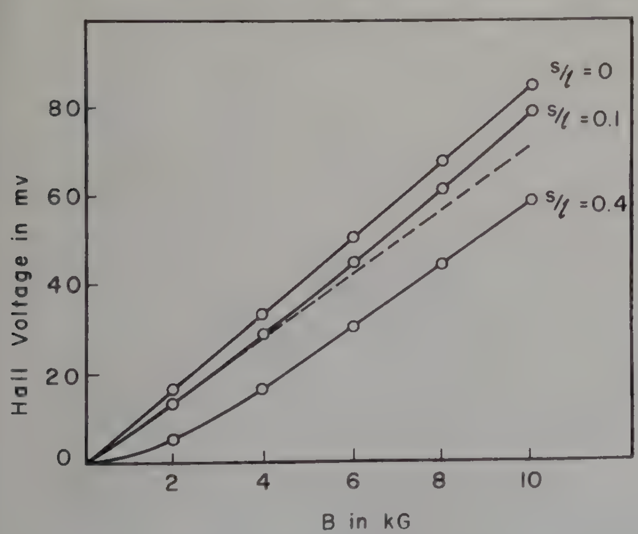

Fig. 3—Variation of Hall voltage with magnetic field in InSb. The different values of s/1 represent the ratio of width to length of the specimen. (Ref. 11)

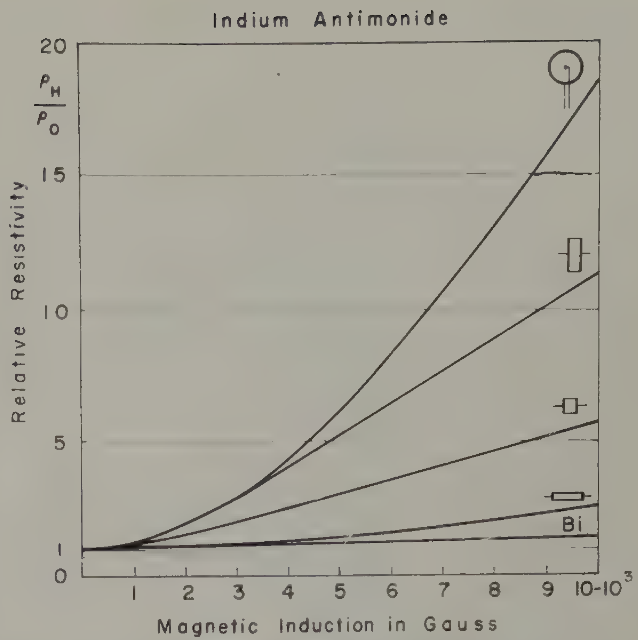

Fig. 6—Variation in resistivity with magnetic field in InSb. The curves are for different specimen geometries. (Ref. 2)

If an InSb slug is connected as shown in Fig. 5, the network is nonreciprocal in the sense that power is transmitted in one (forward) direction and attenuated in the other (reverse) direction. The direction of transmission depends on the direction of the magnetic field. The device acts as a switch, although attenuation in the reverse direction is not as high as might be desired.

As a result of the high electron mobility of InSb, the magnetoresistive effect is very strong. Specialized geometries have been developed to provide maximum resistance change per unit change in magnetic field strength. The curves of Fig. 6 show relative resistivity versus magnetic induction for a long rod, a square plate, an oblong plate with the electrodes on the long side, and a Corbino disk. The Corbino disk, which provides the maximum magnetoresistive effect, is shown in Fig. 7. Figure 8 illustrates another method of increasing the effect by interconnecting rectangular plates by means of shorting strips.

Because InSb has a low energy gap, p-n junctions are masked at room temperature by the high intrinsic carrier concentration. At liquid-nitrogen temperature, however, the electrical effects of p-n junctions can be observed. Some junctions are very sensitive photovoltaic detectors.[9] The edge of a grown junction is generally used for this purpose, but the out-diffused broad area junctions previously mentioned have also been employed. The low energy gap, high electron mobility and short lifetime combine to provide a fast response detector sensitive to wavelengths up to 6 microns. This cutoff wavelength corresponds to an energy greater than the intrinsic gap of 0.18 ev. This is because of the degeneracy effect mentioned above,

which ordinarily occurs in n-type material at liquid nitrogen temperatures.

A photocell based on the PEM effect has also been developed.[13] Since this effect does not depend on the existence of p-n junctions, the device can operate at room temperature where the sensitivity extends to about 7 microns. The PEM cell is an exceptionally low-noise device because there is neither junction noise nor current noise. These photocells are expected to extend greatly the sensitivity of infrared spectrographic equipment, and they will be of considerable importance in military applications.

Indium Arsenide

Preparation. Arsenic has a vapor pressure of several atmospheres at 940°C, the melting point of InAs;[14] fortunately the vapor pressure of indium is negligibly small. The compound must be synthesized in a sealed tube, the walls of which are heated.

Two methods can be used to prevent the pressure in the tube from exceeding one atmosphere. In the first method a double furnace is used, as shown in Fig. 9.[15] The lower half of the furnace is heated to about 1000°C so that an InAs skin is prevented from forming. The upper half is kept at approximately 600°C, at which the arsenic vapor pressure is one atmosphere. The arsenic vapor pressure over molten InAs is less than an atmosphere, however, so that as the reaction proceeds arsenic distills into the molten InAs solution. On cooling the furnace the InAs phase separates from the melt. The reaction takes several days to complete, since it depends on diffusion and convection to mix the melt.

The second and quicker method of preparing InAs is shown in Fig. 10. Indium is placed in a boat and the boat, along with the arsenic, is put in a sealed, evacuated tube. Thermocouples, attached to the ends of the capsule, are used to control the side furnaces and maintain a temperature of 600°C. As the molten zone passes through the indium, arsenic dissolves and InAs freezes out.

Purification. At present there is no really satisfactory way to purify arsenic. It sublimes at 640°C and melts at 850°C at a pressure of about 37 atmospheres. Zone refining has so far been found to be impracticable; consequently arsenic is purified by repeated fractional sublimation. Other schemes have been suggested, but

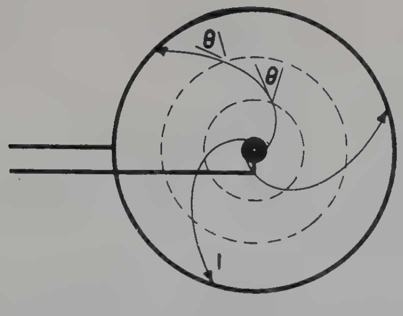

Fig. 7—Corbino disk for maximum magnetoresistance effect. (Ref. 2)

satisfactory operation has not been reported. To remove sulfur and selenium, which are particularly troublesome, it has been proposed to distill the arsenic into molten lead and then distill the arsenic out of the lead. Another proposed scheme is to zone refine arsenic trichloride, the idea being that the troublesome impurities will segregate more readily from the freezing compound than from the subliming metal.

The apparatus shown in Fig. 10 can obviously be used to zone refine InAs. An extensive study has been made of the segregation coefficients of various elements in this compound.[16] These are as follows:

Element	Segregation Coefficient
Mg	0.70
Zn	0.77
Cd	0.13
Si	0.40
Ge	0.07
Sn	0.09
S	1.00
Se	0.93
Te	0.44

The volatile impurities S and Se cannot be removed by zone refining; the unity segregation coefficient is not so much a reflection of the partition of impurity between the solid and liquid as it is an indication that compressed gas such as nitrogen. The pressure in the tube is made equal to the phosphorus vapor pressure, so that the metal wall rather than the quartz capsule takes the pressure difference. There are several difficulties in this scheme and no report of its use has yet appeared.

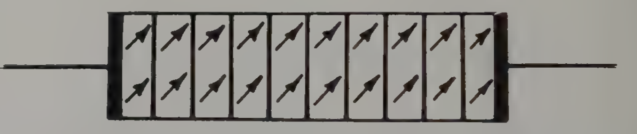

Fig. 8—Bar sample with shorting strips to increase the magnetoresistive effect. (Ref. 2)

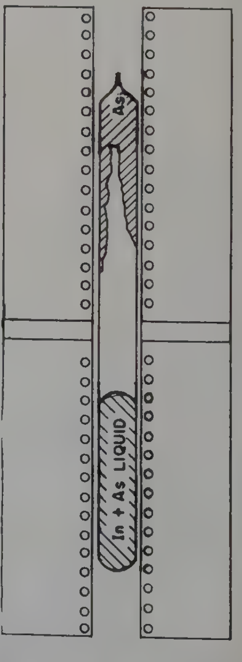

Fig. 9—Vertical furnace for synthesis of compounds with a volatile constituent.

the impurity can be evaporated from one portion of the ingot to another.

Single Crystal Growth. Small single crystals of InAs have been grown by a modification of the Czochralski technique[17] as shown in Fig. 11. The unique features of this procedure are that the pulling is done in a sealed capsule, the walls of which are heated, and a magnet is used to pull the crystal. No other method of growing InAs single crystals has been reported, but it is the author's belief that almost any method now used for growing germanium single crystals can be successfully modified for intermetallic compounds.*

Properties and Application. In its semiconducting properties, InAs is very much like InSb. The energy gap of InAs is slightly higher, but the electron mobility is lower. Degeneracy in n-type material has been observed[18,19] as well as the high magnetoresistance effect. Although neither a PEM nor a photoconductive effect has been reported, the photovoltaic effect has been observed in junctions which occur naturally in polycrystalline ingots.[19]

All the conductivity-type devices that have been made with InSb have also been made with InAs. The InAs devices are in general not quite as sensitive as those made with InSb, but their properties change less with variations in temperature.

Indium Phosphide

Preparation. Phosphorus may be more difficult than arsenic to purify. There is a complex relationship among the various solid phases of phosphorus which makes its fractional distillation and zone refining in-

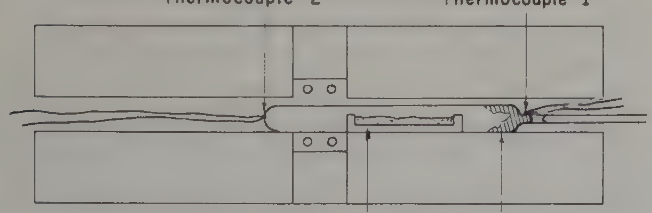

Fig. 10—Zone melting furnace for synthesis of compounds with a volatile constituent.

tricate processes. The vapor pressure over white phosphorus at its melting point (44°C) is less than one mm. Unless the hydrostatic pressure on the liquid phase is approximately 20 atmospheres, however, the liquid will transform to the solid violet phase which melts at 590°C at a vapor pressure of 43 atmospheres. A zone refining scheme for violet phosphorus has been suggested.[20] The element is sealed in a quartz capsule which is in turn placed in a closed metal tube. The tube is attached by copper tubing to a cylinder of

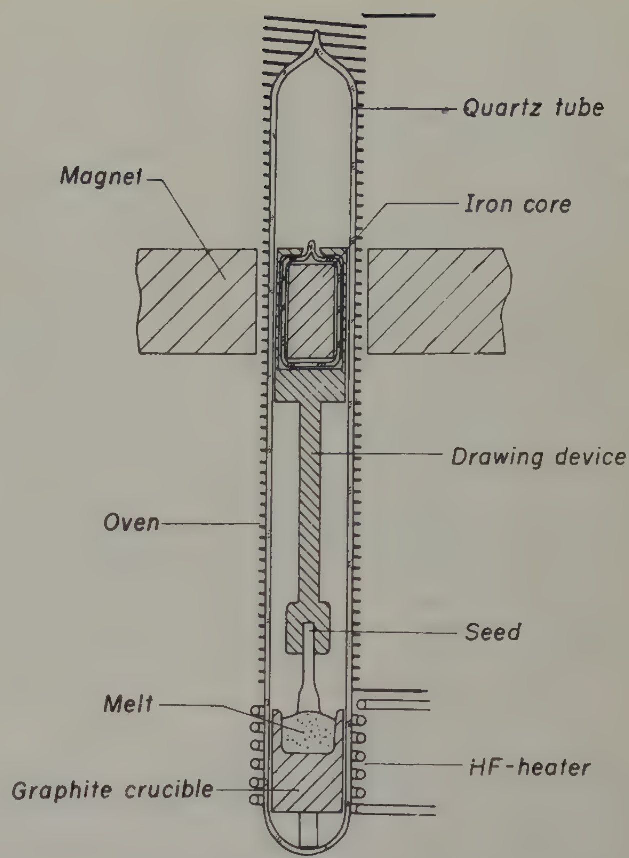

Fig. 11—Czochralski technique adapted for compounds with a volatile constituent. (Ref. 2)

Indium phosphide melts at 1070°C. The vapor pressure of phosphorus over molten stoichiometric InP is five atmospheres.[21] The melting point can be lowered slightly by adding a stoichiometric excess of In. The phosphorus vapor pressure over such a nonstoichiometric melt is drastically lowered. This means, in effect, that if the side furnaces of Fig. 10 are operated at 1010°C, so that the phosphorus pressure is one atmosphere, the composition of the molten zone will deviate considerably from stoichiometry. As noted in connection with InSb, in InP there also seems to be a negligibly small solid solubility of In, so that a stoichiometric solid will crystalize from a nonstoichiometric melt. In this manner InP can be synthesized and presumably zone refined. Details of a suitable zone refining process have not been reported, and there is no record of large single crystals having been grown.

Properties and Applications. Indium phosphide has an energy gap of approximately 1.3 ev at room temperature. The electron mobility is 3400 cm^2/volt sec while the hole mobility is only 50 cm^2/volt sec at room temperature. Little research on InP has been reported in the literature, and apparently no striking effects have been discovered in the pure compound. InAs and InP, however, are completely miscible in both the liquid and solid phases. Solid solutions of InP and InAs cover the range of energy gap continuously from 0.3 ev to 1.3 ev.[22] Figure 12 shows the variation with solution

*Folberth has recently grown single crystals of InAs by passing a molten zone through a horizontal ingot, while Strauss has used temperature gradient freezing. Kolm has adapted the more conventional Czochralski technique to volatile compounds. In order to grow untwinned single crystals, the melt must be almost exactly stoichiometric.

composition of the energy gap at 0°K and electron mobility.

Rectification has been observed in InP although it is more characteristic of a Schottky type barrier than the minority carrier injection phenomenon observed in Ge. InP presently available has too small a lifetime and, hence, diffusion length to enable it to be used for devices based on injection, *e.g.*, transistors. In theory, however, there is no reason why InP of sufficient purity cannot be prepared so that the diffusion length is comparable with that in Ge. Devices made from such material would perform better at high temperatures than devices made from either Ge or Si, since InP has a higher energy gap than both of these elements. It might be suspected that since InAs-InP mixed crystals have higher mobilities than pure InP, the diffusion length of InP could be increased by the addition of InAs. This is true, but an inspection of Fig. 12 shows that a mixture with an appreciably greater mobility than InP would have an energy gap less than that of Ge.

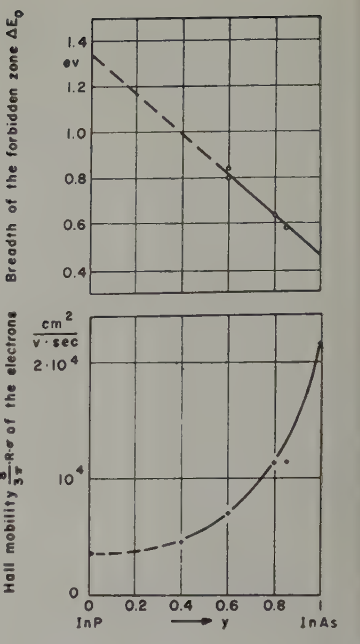

Fig. 12—Variation of energy gap and electron mobility with composition of InP, InAs alloys; y is the mole fraction InAs. (Ref. 2)

Gallium Arsenide

Preparation. Because of the difficulty in preparing InP, more work has been done on GaAs, which has almost identical semiconducting properties and is easier to prepare. GaAs melts at 1238°C, and the vapor pressure of arsenic over the stoichiometric melt is only about one atmosphere. Therefore all the methods of preparation, purification and single crystal growth that were described for InAs are applicable to GaAs. Gallium metal is not, however, so easily purified as indium. It melts at 30°C and it cannot readily be zone refined because it supercools easily. Some purification has been achieved by zone refining $GaCl_3$ (mp 80°C) and recovering the metal electrolytically.[23]

GaAs can be zone refined fairly readily. Donor impurities, probably sulfur and selenium, are the most difficult to remove. It should be pointed out that at room temperature the intrinsic electron concentration of GaAs is of the order of 10^7 per cc, so that the attainment of intrinsically pure material is virtually impossible. A practical difficulty arises in the zone refining of GaAs because of the gradual devitrification of the quartz capsule containing the boat (See Fig. 10). This limits the number of zone passes that can be made before the boat must be re-encapsulated. Molten gallium arsenide attacks quartz; therefore, either graphite boats are used, or quartz boats are carbon coated by the pyrolytic decomposition of methane.

GaAs single crystals have been grown both by the Czochralski technique described for InAs[17] and by the floating zone method.[24] Coarse-grained ingots are readily produced by cooling the melt slowly[25] and by zone refining, although in the latter case extensive twinning usually occurs.

Properties. Considerably more work has been reported on GaAs than on InP. The energy gap of GaAs at room temperature is 1.38 ev as determined from the optical absorption edge.[26] From the temperature dependence of the Hall coefficient and resistivity, energy gaps between 1.35 and 1.25 ev have been reported.[25,27] The long wavelength limit of photoconductivity has indicated an energy gap as low as 1.1 ev,[15] while the cutoff wavelength of the photovoltaic effect[28] has shown a gap of 1.35 ev. Radiation emitted when holes and electrons recombine has been reported;[29] the maximum in this radiation was observed at a wavelength corresponding to an energy of 1.1 ev. Mixed crystals of gallium arsenide-gallium phosphide have been made;[30] the energy gaps range from 1.35 to 2.3 ev.

Most recent measurements on GaAs yield an electron mobility of about 8000 cm^2/volt sec at room temperature, but there are indications that in very pure material it may be as high as 12000. The mobility ratio is approximately 12. The high electron mobility is again typical of the III-V semiconductors. The effective mass for electrons is only 0.06 m_0. This is not as low as in InSb, but lower than in Ge. Impurity band conduction has been observed[25] for both *n*- and *p*-type material. In purer material discrete acceptor states have also been observed at 0.0015 and 0.001 ev above the valence band.[25] From resistivity and photoconductive data there is also evidence for trapping levels lying deep in the forbidden gap. These traps may be associated with oxygen atoms. In addition there may be impurity recombination centers, but no evidence of their effectiveness has been reported. Lifetimes in GaAs are estimated to be of the order of 0.01 μsec. This estimate and the fact that the energy of the radiation accompanying recombination corresponds fairly closely to the energy gap indicate that direct recombination may predominate over impurity-catalyzed indirect recombination. On the other hand, the difference between the 1.1 ev maximum in the recombination radiation and the 1.35 ev optical and thermal energy gap, if significant, would indicate the

existence of a recombination center at about 0.25 ev from the top or bottom of the forbidden gap. If indirect recombination is the dominant process as in germanium, then purification can appreciably increase the lifetime.*

Applications. Theoretical calculations[31] show that *p-n* junctions in GaAs should be efficient solar-energy converters. Solar batteries having surface junctions have been made by the diffusion of zinc into *n*-type material. These batteries have not been made reproducibly but efficiencies as high as 6.5% have been reported.[28] GaAs photocells appear to have a quantum efficiency of unity in the near infrared, but response to X-radiation has also been observed.[32]

Both low-frequency and microwave diodes have been made with GaAs. A plate rectifier with a breakdown voltage of 150 volts and a rectification ratio of about 20,000 has been reported.[33] A microwave diode having a conversion loss of only 6 db has been produced.[34] Alloy junctions have been prepared, and one alloy junction transistor showed a gain of 36 db.[34] Actually, since GaAs has a high mobility ratio, unipolar devices made from it are more efficient than bipolar devices. A unipolar transistor with a transconductance of 0.1 ma/volt has been made.[34] These performance figures are comparable with those of Ge and Si devices.

At present GaAs is most promising as a competitor to silicon and germanium, and a small but significant research and development program on this material is being pursued in our Research Laboratories at Bayside.

Cadmium Telluride

III-V compounds of the type discussed above are not, of course, the only ones with a zincblende structure. In fact, the mineral zincblende itself is one crystalline form of zinc sulfide. Zinc sulfide is a II-VI compound, and although it is more like an insulator than a semiconductor, several other II-VI compounds are definitely semiconductors. Among them is cadmium telluride, CdTe, which also has the zincblende structure.

Preparation. The compound CdTe melts at 1045°C. Its synthesis presents a problem, since at the melting point of the compound both cadmium liquid and vapor attack quartz. By using a graphite crucible sealed in a quartz capsule, the deterioration of the capsule can be minimized if the synthesis is carried out rapidly.[35] Once the compound is synthesized, single crystals can be grown fairly readily by the Bridgman technique using a graphite crucible with a conical bottom. In theory the compound can also be zone refined, but success has not been reported. The elements are usually zone refined before synthesis.

Properties and Applications. CdTe has an energy gap of 1.45 ev as determined by optical absorption measurements.[36] The electron mobility is reported to be 300 cm^2/volt sec.[37] The compound has two types of donor impurities and two types of acceptor impurities. Examination of the periodic table shows that the halogens will substitute for Te as donors, while the Group III elements such as Ga and In substitute as donors for Cd. Similarly, the Group I elements such as Cu and Ag, and the Group V elements (P,Sb), are acceptors substituting for Cd and Te respectively. Acceptor impurities have been noted to have much higher activation energies than donor impurities regardless of whether or not the substitution is for the Cd or Te atom.[36] The preparation of high-purity CdTe has not been reported; furthermore, there is evidence for a high degree of compensation of impurities, which would complicate somewhat the interpretation of resistance and Hall effect data.

Because of its high energy gap CdTe is sometimes mentioned as being potentially a good material for solar batteries.[31] Point-contact rectification has also been experimentally observed on CdTe.

Mercuric Telluride**

Preparation. HgTe is another II-VI compound with the zincblende structure. It melts at 650°C and is relatively easy to prepare. The purified elements are sealed in an evacuated quartz capsule which is then put into a simple furnace. The temperature is gradually raised, and by the time the melting point of tellurium (452°C) has been reached, most of the tellurium is dissolved in the mercury. This lowers the vapor pressure of the mercury to a manageable degree. The capsule is then heated above the melting point of HgTe and the liquid is allowed to soak with occasional agitation for 24 hours. The melt is then slowly cooled to room temperature. Single crystals can readily be grown in the same capsule by either the Bridgman method or the horizontal zone technique. The latter method has the advantage of permitting zone refining and crystal growth to be done in the same apparatus, which is of the type shown in Fig. 10. The cold-zone temperature is about 550°C, corresponding to a mercury vapor pressure of about three atmospheres. This is the estimated pressure above the molten compound. Unlike the case with III-V compounds, it is not certain whether the stoichiometric compound will always crystallize out of a nonstoichiometric melt. Nor is the efficacy of zone refining known, since no change in carrier concentration

*Lifetimes of about 10 μsec have recently been reported in purified gallium arsenide.

**The material presented in this section on HgTe represents work done at our Research Laboratories by J. Black, S. M. Ku, and A. R. Liboff. Some research on HgTe has been privately communicated to us by T. C. Harmon of the Battelle Memorial Institute, but the results were of a tentative nature. Qualitatively they are in agreement with our own. R. O. Carlson of the General Electric Research Laboratories has recently published results (*Bull. Am. Phys. Soc.*, Vol. 2, p. 347, 1957) that also agree with our data. It should be noted that the interpretation of data on HgTe has not definitely been confirmed, so that some of the information reported here is also to be regarded as tentative.

has been noted along the length of extensively zone-refined crystals.

This points up the need for purifying the elements before synthesis. Tellurium can be purified by distillation and by zone refining. Since the vapor pressure of Te at its melting point is low, the zone refining can be done in an open system with flowing hydrogen to prevent oxidation and suppress evaporation. Mercury is usually purified by distillation. It can be zone melted in an apparatus similar to that shown in Fig. 13, although it is not known whether this method will purify the mercury. Silver is an impurity that is difficult to remove from mercury by distillation; preliminary experiments on the zone refining of mercury doped with silver show no segregation of the silver, however.

Properties and Applications. Hgte is almost metallic in behavior. It has an energy gap at room temperature of about .02 ev as determined by Hall effect data. The electron Hall mobility is quite high, being about 15,000 cm^2/volt sec at room temperature. The Hall coefficient of intrinsic material is negative, so that the ratio of electron to hole mobility is greater than unity. Although there is a rather large transverse magnetoresistance effect, no longitudinal magnetoresistance has been observed. This is consistent with the constant energy surfaces in the conduction band being spherical. Below about 250°K all material so far studied undergoes a change in properties from those characteristic of intrinsic conduction to those of extrinsic *p*-type conduction. Since the energy gap is quite small, the transition occurs over a large temperature range which extends below 78°K. In the transition region the Hall coefficient decreases markedly with increasing magnetic induction starting as low as 1000 gauss.

All material prepared so far has been *p*-type. This may be due to the presence of a dominating acceptor impurity such as arsenic which is volatile and hence difficult to remove by zone refining in an enclosed tube. On the other hand, the invariant composition of the Hg-Te system may deviate from stoichiometry. This effect will be discussed more fully in connection with the properties of bismuth telluride.

If 15,000 cm^2/volt sec represents the electron mobility when limited by impurity scattering, purification of the compound should greatly increase this figure. Moreover, there is a trend in the zincblende type of semiconductors for materials with a low energy gap to have high mobilities. The indications are, then, that the mobilities in HgTe may be higher than those of InSb. If this is so, many of the devices employing InSb could also be made with HgTe.

Bismuth Telluride

The compounds so far considered all possess the relatively simple cubic zincblende structure, and have properties and applications not unlike those of germanium. Bismuth telluride, however, is a different type of semiconductor with a complex hexagonal structure. It is of interest for applications in thermoelectric power generation and thermoelectric refrigeration.

Preparation. The compound melts at 585°C and is readily synthesized by casting a stoichiometric melt of the elements in a sealed tube. It is current practice to zone refine the elements to spectroscopic purity before synthesis. One method of preparing the material for study has been to grind the cast ingot to powder and to anneal a compact of this powder.[38] It is preferable, however, to work with single crystals of the pure compound. Bi_2Te_3 single crystals have been grown using the Stockbarger technique[39] in which a capsule containing the melt is lowered slowly through a vertical freezing gradient; bismuth-rich single crystals are produced, and tellurium segregates as a separate phase in the last-to-freeze end. The lattice parameters of the crystal change with varying amounts of excess bismuth. All but the last-to-freeze portions were reported to be homogeneous single crystals. On the other hand, in no case were homogeneous crystals with excess tellurium prepared. If the capsule is lowered quickly through the gradient, there is no appreciable segregation of tellurium, but the ingot is polycrystalline. If a melt in a horizontal boat is directionally frozen from one end (normal freezing), Te also segregates.[39]

Single crystals can be prepared by passing a molten zone along an ingot,[40] if care is taken to insure a planar freezing interface.[39] The growth direction is

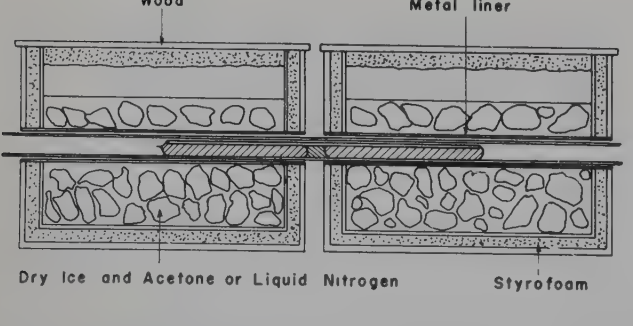

Fig. 13—Zone melter for materials that melt at or below room temperature.

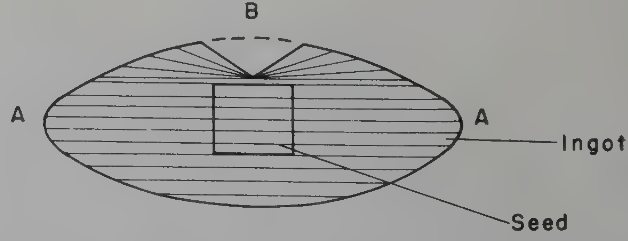

Fig. 14—Schematic cross section of a Bi_2Te_3 crystal pulled from the melt. The cleavage planes are normal to the paper and are indicated by the lines. The growth direction is also normal to the paper. (Ref. 39)

parallel to the basal cleavage plane of the hexagonal structure. Crystals produced by a molten zone are always p-type; however, an n-type polycrystalline region has been reported to form at the last-to-freeze end of an extensively zone-refined ingot.[40]

Bi_2Te_3 single crystals have been grown by the Czochralski technique[39] in which a hydrogen atmosphere was used to minimize evaporation of the tellurium. Since the crystals cleave readily along the (0001) basal hexagonal plane, it is mechanically easier to orient the seed so that the growth direction is in this plane rather than normal to it. The resulting crystals grow more readily along the basal plane, so that they have an oval cross section, often with a characteristic notch as shown in Figs. 14 and 15. All crystals so pulled were p-type.

A portion of the phase diagram[41] of Bi_2Te_3 is shown in Fig. 16. Unlike the III-V systems, there is an appreciable solid solubility of excess Bi and Te in the compound. The maximum melting point occurs on the bismuth-rich side of the stoichiometric composition. In order to grow ingots with excess tellurium, the melt must be rich in that element. The zone melting furnace of Fig. 10 may be used for this purpose. If the temperature of the cold sink is sufficiently high, the tellurium vapor will be in equilibrium with the liquid at compositions at or to the right of A in Fig. 16. In turn, this liquid will be in equilibrium at the freezing interface with solid which is stoichiometric or rich in Te.[42] Tellurium rich ingots have been prepared under these conditions.[43]

Properties. Bismuth telluride is of considerable practical importance because of its relatively efficient performance for thermoelectric refrigeration and thermoelectric power generation. The efficiency for both applications is governed by a figure of merit[48] $Z = \alpha^2/\rho\lambda$ where α is the thermoelectric power, ρ the electrical resistivity and λ the thermal conductivity. A relatively large value of Z is required for efficient operation. A qualitative explanation of the nature of this figure of merit will be given in the following section on applications, in which thermoelectric devices are discussed. In the present section the fundamental properties α, ρ, and λ will be described.

The thermoelectric power, $\alpha = d\theta/dT$, of a material is the potential difference $d\theta$ induced by a temperature difference dT across a sample. In metals and extrinsic semiconductors it represents the energy (relative to the Fermi level) transmitted by a charge carrier along the sample per degree temperature difference. For metals and very impure (degenerate) semiconductors this is quite small. For fairly pure extrinsic semiconductors the thermoelectric power is over ten times that of metals. The sign of the thermal voltage is determined by the sign of the dominant carrier as in the Hall effect. For n-type material the hot junction is positive. The thermoelectric power of intrinsic semiconductors is zero if the electrons and holes have the same mobility. On the other hand, if the electrons

Fig. 15—Bismuth telluride crystal pulled from the melt. (Ref. 39)

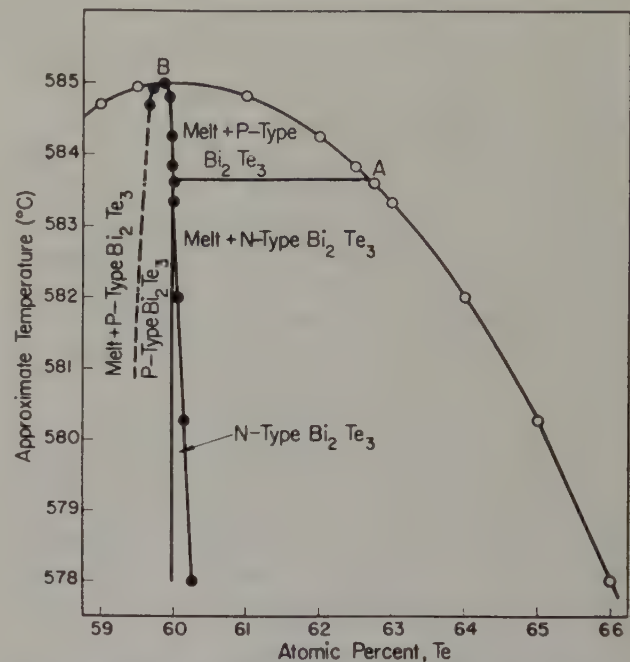

Fig. 16—Phase diagram of the bismuth telluride system. (Ref. 41)

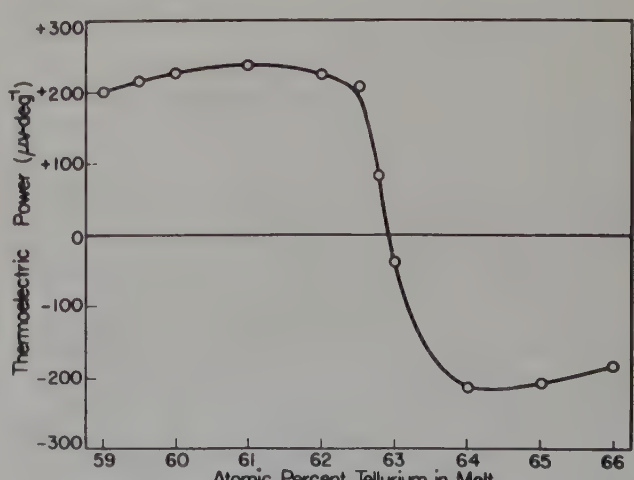

Fig. 17—Thermoelectric power of Bi_2Te_3 single crystals as a function of composition of the melt from which the crystal was grown. (Ref. 41)

have a higher mobility than the holes, as in most semiconductors including Bi_2Te_3, the thermoelectric power of intrinsic material is negative. Figure 17 shows the variation of the thermoelectric power of Bi_2Te_3 at room temperature as a function of the melt composition used to prepare the material. A thermocouple made from p- and n-type material will produce a maximum thermoelectric power of about 500 μvolts/°C, which is over ten times the corresponding figure for a chromel-alumel thermocouple.

The thermoelectric power of most semiconductors is high. Bi_2Te_3 is a favorable material for thermoelectric applications not only because of its high thermoelectric power but also because the product $\rho\lambda$ of the electrical resistivity and thermal conductivity is low. To describe why $\rho\lambda$ should be lower for Bi_2Te_3 than for most other common semiconductors, a brief discussion of the theory of thermal conductivity is helpful.

The total thermal conductivity can be considered as the sum of λ_0, the contribution of the atomic lattice vibrations, and λ_e, the contribution of the current carriers. Interactions such as phonon drag between the lattice and the carriers are neglected in this discussion. In metals, where the electron concentration is of the order of $10^{22}/cm^3$, λ_e predominates. In semiconductors, on the other hand, for a carrier concentration of $10^{18}/cm^3$ or less, $\lambda_e < \lambda_0$ as is indicated in Table II.

TABLE II

Thermal Conductivities at Room Temperature

Semiconductor	ρ in ohm-cm	λ_0 in watt/ cm-deg	λ_e in watt/ cm-deg
InSb[46]	0.005	0.153	2.36×10^{-3}
Ge[43]	4.9	0.540	5.95×10^{-6}
Bi_2Te_3	0.00033	0.015	1.4×10^{-3}

For metals and extrinsic semiconductors λ_e is closely related to ρ. In fact, the well-known Wiedmann-Franz law states that $\lambda_e\rho$ is a constant at a given temperature independent of the material. It has been further discovered that for extrinsic semiconductors in which the resistivity is governed by lattice scattering, $\lambda_0\rho$ decreases roughly as the mean atomic weight of the material increases.[44] Bi_2Te_3 has a mean atomic weight of approximately 160 which is quite high compared to materials such as Ge and InSb. It has been experimentally demonstrated[45] that Bi_2Te_3 has a very low value of $\lambda_0\rho$ as can be seen from Table II. Hence the product $\rho\lambda = \rho\lambda_e + \rho\lambda_0$ is lower for Bi_2Te_3 than for any other of the extensively studied semiconductors. It has been suggested[48] that λ_0 can be lowered in Bi_2Te_3 by the introduction of impurities that selectively damp lattice vibrations. These impurities would have to be of such a nature that the resistivity is not increased by a reduction of the carrier mobility, nor could the thermoelectric power be appreciably reduced.

The electronic thermal conductivity of intrinsic material is much greater than that of extrinsic material. In the latter case the thermal transport occurs merely by the transfer of kinetic energy from the carriers at the heat source to those at the sink. For intrinsic material another mechanism is possible. Heat is absorbed at the source by the thermal generation of hole electron pairs, while their recombination at the sink gives off heat. For intrinsic Bi_2Te_3 this "ambipolar" electronic thermal conductivity exceeds the normal electronic thermal conductivity by a factor of 12[44].

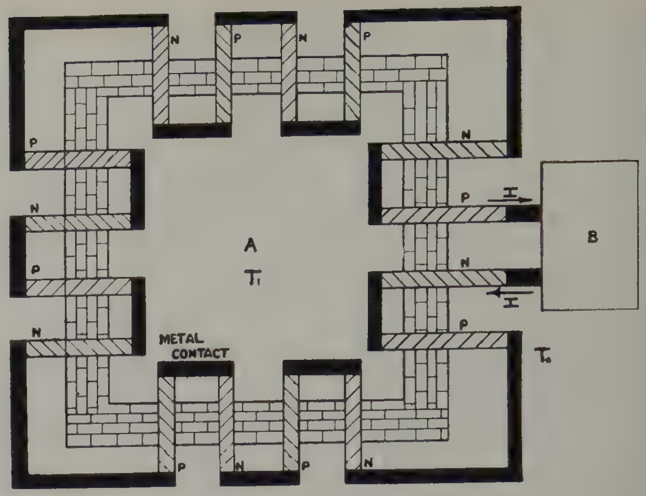

Fig. 18—As a thermoelectric power generator, A is a heat source such as a firebox or heat exchanger; B is a d-c motor. As a thermoelectric cooler, A is the interior of a room or refrigerator, while B is a d-c generator. In both cases current flows as indicated by I. N and P indicate semiconductor legs of the thermocouples which are connected in series by heat exchanging metal buss bars.

In other respects Bi_2Te_3 is a fairly typical semiconductor. The energy gap at room temperature is 0.145 ev.[43] The hole mobility at room temperature is about 400 cm²/volt-sec and the mobility ratio is two. It should be noted, however, that these electrical measurements are made *parallel* to the cleavage plane. Now there is a pronounced anisotropy in the thermal conductivity, so that there is good reason to believe that different mobilities would be determined from electrical measurements *normal* to the cleavage plane.

A stoichiometric excess of tellurium acts as an n-type impurity while an excess of bismuth acts as a p-type impurity. This is consistent with the observation that tellurium segregates to the last-to-freeze end of a zone refined ingot; such ingots are always p-type up to the point, if it exists, where the molten zone has composition indicated by point A in Fig. 16. As added impurities, lead is an acceptor while iodine is a donor.[43]

Applications. Bi_2Te_3 is a promising material for thermoelectric generators and refrigerators. The former device would convert thermal energy directly to electric power without the use of steam engines and dynamos. A schematic diagram of a thermoelectric generator is shown in Fig. 18. If T_1 is the hot junction temperature and T_0 the cold junction, the theoretical maximum conversion efficiency of heat into

$$\eta = W/Q_1 = (T_1 - T_0)/T_1.$$

For a thermoelectric generator η is reduced by a factor $\beta < 1$ which depends on the figure of merit

$Z = \alpha^2/\lambda p$, where α = thermoelectric power, p represents the loss in efficiency due to joule heating in the thermocouple material, and λ represents the heat energy not converted to work because of direct thermal conduction in the material. In the limits $Z \rightarrow 0$ and $Z \rightarrow \infty$, β goes to zero and unity respectively.

The importance of Bi_2Te_3 as a thermoelectric material can now be explained. Owing to its low lattice thermal conductivity Bi_2Te_3 has the lowest λ of any known semiconductor, while its α and p are comparable with those of other semiconductors. For Bi_2Te_3 $Z \sim 10^{-3}$ deg^{-1} while it is at least an order of magnitude lower for metals and the more conventional semiconductors. The highest value of Z reported to-date is 3.5×10^{-3} deg^{-1} for an alloy of bismuth telluride and antimony telluride.[48]

Efficient operation of semiconductors for thermoelectric application is limited to the extrinsic temperature range of the material. In the intrinsic range the thermal conductivity increases excessively owing to the ambipolar phenomenon previously discussed. Moreover, a hot junction which is formed from the contact of p-type and n-type material will at high temperatures be p-intrinsic or n-intrinsic depending on whether the ratio of electron to hole mobility is less than or greater than unity. This will greatly lower the thermoelectric power of the hot junction. It is for this reason that the most successful applications of Bi_2Te_3 thermocouples have been in thermoelectric cooling. Figure 18 shows a schematic diagram of a thermoelectric refrigeration unit. In this application current flows through two junctions in series. One is at a cold temperature T_1 and the other is at room temperature T_0. In addition to the joule heating which occurs in the circuit, the current flow is such that heat is removed from the cold junction and is generated at the hot junction. This is the Peltier effect which is closely related to the thermoelectric effect; in fact $d\theta/dT = \pi/T$ where π is the Peltier coefficient defined as the heat emitted per second per unit current flowing through the junction.

A coefficient of performance may be defined[49] as $k = Q/W$ where Q is the heat transferred from the cold junction to the hot junction and W is the electrical work required to effect the transfer. The theoretical coefficient is $k_{th} = T_1/(T_0 - T_1)$. If joule heating in the circuit and thermal conduction from the hot to the cold junction are taken into account, the coefficient of performance is governed by the same figure of merit that was discussed in connection with the thermoelectric generator. Referring to Fig. 18, for $Z = 2 \times 10^{-3}$ and $T_0 = 300°K$, the lowest temperature T_1 attainable in a well-insulated refrigerator is $-30°C$. Temperatures as low as this have been experimentally recorded. The Russians have made a thermoelectrically cooled commercial refrigerator of 1.4 cu. ft. capacity having 5-inch-thick insulated walls.[50] Seventy-five watts dc are initially required to cool the interior to 0°C and 55 watts are needed to maintain this temperature with an ambient temperature of 20°C. The inventors claim that this is the best performance so far achieved, and that improvements will soon lead to a thermoelectrically cooled refrigerator that will be competitive with compressor types.

Conclusions

Perhaps the largest single obstacle to the more widespread application of compound semiconductors is the fact that in presently available materials excess carrier lifetimes are extremely short. The factors affecting lifetime have been extensively studied in germanium and high purity has been shown to be essential (although it is not sufficient). In compound semiconductors the starting element must be highly purified, since it appears that only limited purification can be effected after synthesis of the compound. Until very recently germanium and silicon were the only elements available in semiconductor grade purity. Many suppliers of other elements such as gallium and arsenic have undertaken research programs on the purification of their products, and better material is continually becoming available. There is no evidence that high energy gap compounds cannot have lifetimes comparable with those observed in germanium and silicon if the compounds are sufficiently pure and perfect in structure. All the semiconductor technology developed for the elements can be adapted to the compounds, and it appears almost inevitable that the solid-state engineer will soon be able to select from a variety of materials a semiconductor best suited for his particular application.

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QSC— Qutronic Semiconductor Corp.
RAY— Raytheon Manufacturing Company
RCA— Radio Corporation of America, Semiconductor Div.
RRC— Radio Receptor Co., Inc.
SAR— Sarkes Tarzian, Inc., Rectifier Division
SEM— Semi-Metals Inc.
SIE— Siemens & Halske Aktiengesellschaft
SSD— Sperry Semiconductor Division
STC— Shockley Transistor Corp.
STCB— Standard Telephone & Cables, Ltd.
SYL— Sylvania Electric Products, Inc.
TFKG— Telefunken, Ltd.
THE— Thermosen, Inc.
TI— Texas Instruments, Inc.
TKD— Tekade, Nurnberg, Germany
TOK— Tokyo Tsushin Kogyo, Ltd.
TRA— Transitron Electronic Corp.
TSC— Trans-Sil Corp.
USD— United States Dynamics Corp.
USS— U. S. Semiconductor Products, Inc.
WEC— Western Electric Co.
WEST— Westinghouse Electric Corp.

CHARACTERISTICS CHART of DIODES and RECTIFIERS

TYPE NO.	USE (See Code Below)	MAT	PIV	MAX. CONT. WORK. VOLT.	Min. Forward Current @ 25°C		MAX. D.C. OUTPUT CURRENT[4]	@ T (°C)	MAX. FULL LOAD VOLT. DROP[4]	Max. Rev. Current			MFR. (See code at start of charts)
					I_f	@ E_f				I_b	@ E_b	@ T	
			(volts)	(volts)	(mA)	(volts)	(amps)		(volts)	(uA)	(volts)	(°C)	
1N1169A†	1	Si	400	400	1000	1.25	.52	100A	.60	100	400	25J	WEST
1N1330†	2	Si	50	50	80A	1.0	240	100	.60	50ma	50	25	WEST-6
1N1331†	2	Si	100	100	80A	1.0	240	100	.60	50ma	100	25	WEST-6
1N1332†	2	Si	150	150	80A	1.0	240	100	.60	50ma	150	25	WEST-6
1N1333†	2	Si	200	200	80A	1.0	240	100	.60	50ma	200	25	WEST-6
1N1334†	2	Si	300	300	80A	1.0	240	100	.60	50ma	300	25	WEST-6
1N1376†	2	Si	50	50	80A	1.0	240	100	.60	50ma	50	25	WEST-6
1N1377†	2	Si	100	100	80A	1.0	240	100	.60	50ma	100	25	WEST-6
1N1378†	2	Si	150	150	80A	1.0	240	100	.60	50ma	150	25	WEST-6
1N1379†	2	Si	200	200	80A	1.0	240	100	.60	50ma	200	25	WEST-6
1N1380†	2	Si	300	300	80A	1.0	240	100	.60	50ma	300	25	WEST-6
1N1486†	1	Si	500	500	1000	1.25	.22	100A	.50	3500	500	100A	WEST-6
1N1537†	1	Si	50	50	1000	1.25	1.6	140C	.70	50	50	25J	WEST-6
1N1538†	1	Si	100	100	1000	1.25	1.6	140C	.70	50	100	25J	WEST-6
1N1539†	1	Si	150	150	1000	1.25	1.6	140C	.70	50	150	25J	WEST-6
1N1540†	1	Si	200	200	1000	1.25	1.6	140C	.70	50	200	25J	WEST-6
1N1541†	1	Si	300	300	1000	1.25	1.6	140C	.70	50	300	25J	WEST-6
1N1542†	1	Si	400	400	1000	1.25	1.6	140C	.70	50	400	25J	WEST-6
1N1543†	1	Si	500	500	1000	1.25	1.6	140C	.70	50	500	25J	WEST-6
1N1544†	1	Si	600	600	1000	1.25	1.6	140C	.70	50	600	25J	WEST-6
1N1625	1	Se	48	22	.10ua	1.0	250ua	100A		15	26	25	INRC
1N1625A	1	Se	48		.20ua	1.0	500ua	100A		15	26	25	INRC
1N1626	1	Se	96		.10ua	2.0	250ua	100A		15	52	25	INRC
1N1626A	1	Se	96		.20ua	2.0	500ua	100A		15	52	25	INRC
1N1627	1	Se	48		1.5ua	1.0	3.75ma	100A		27	26	25	INRC

CHARACTERISTICS CHART of DIODES and RECTIFIERS

TYPE NO.	USE (See Code Below)	MAT	PIV (volts)	MAX. CONT. WORK. VOLT. (volts)	Min. Forward Current @ 25°C I_f (mA)	@ E_f (volts)	MAX. D.C. OUTPUT CURRENT[4] (amps)	@ T (°C)	MAX. FULL LOAD VOLT. DROP[4] (volts)	Max. Rev. Current I_b (uA)	@ E_b (volts)	@ T (°C)	MFR. (See code at start of charts)
1N1628	1	Se	96		1.5ua	2.0	3.75ma	100A		27	52	25	INRC
1N1629	1	Se	144		1.5ua	3.0	3.75ma	100A		27	78	25	INRC
1N1630	1	Se	192		1.5ua	4.0	3.75ma	100A		27	104	25	INRC
1N1631	1	Se	240		1.5ua	5.0	3.75ma	100A		27	130	25	INRC
1N1632	1	Se	288		1.5ua	6.0	3.75ma	100A		27	156	25	INRC
1N1633	1	Se	336		1.5ua	7.0	3.75ma	100A		27	182	25	INRC
1N1634	1	Se	384		1.5ua	8.0	3.75ma	100A		27	208	25	INRC
1N1635	1	Se	48		5.0ua	1.0	12.5ma	100A		108	26	25	INRC
1N1636	1	Se	96		5.0ua	2.0	12.5ma	100A		108	52	25	INRC
1N1637	1	Se	144		5.0ua	3.0	12.5ma	100A		108	78	25	INRC
1N1638	1	Se	192		5.0ua	4.0	12.5ma	100A		108	104	25	INRC
1N1639	1	Se	240		5.0ua	5.0	12.5ma	100A		108	130	25	INRC
1N1640	1	Se	48		11ua	1.0	28ma	100A		240	26	25	INRC
1N1641	1	Se	96		11ua	2.0	28ma	100A		240	52	25	INRC
1N1642	1	Se	144		11ua	3.0	28ma	100A		240	78	25	INRC
1N1660†	2	Si	50	50	52A	1.0	160	100	.60	40ma	50	25	WEST-6
1N1661†	2	Si	100	100	52A	1.0	160	100	.60	40ma	100	25	WEST-6
1N1662†	2	Si	150	150	52A	1.0	160	100	.60	40ma	150	25	WEST-6
1N1663†	2	Si	200	200	52A	1.0	160	100	.60	40ma	200	25	WEST-6
1N1664†	2	Si	300	300	52A	1.0	160	100	.60	40ma	300	25	WEST-6
1N1665†	2	Si	400	400	52A	1.0	160	100	.60	40ma	400	25	WEST-6
1N1666†	2	Si	500	500	52A	1.0	160	100	.60	40ma	500	25	WEST-6
1N1670†	2	Si	50	50	80A	1.0	240	100	.60	50ma	50	25	WEST-6
1N1671†	2	Si	100	100	80A	1.0	240	100	.60	50ma	100	25	WEST-6
1N1672†	2	Si	150	150	80A	1.0	240	100	.60	50ma	150	25	WEST-6
1N1673†	2	Si	200	200	80A	1.0	240	100	.60	50ma	200	25	WEST-6
1N1674†	2	Si	300	300	80A	1.0	240	100	.60	50ma	300	25	WEST-6
1N1680	2	Si	150	150			35	125C					INRC
1N1681	2	Si	250	250			35	125C					INRC
1N1682	2	Si	300	300			35	125C					INRC
1N1683	2	Si	350	350			35	125C					INRC
1N1684	2	Si	400	400			35	125C					INRC
1N1685	2	Si	450	450			35	125C					INRC
1N1686	2	Si	500	500			35	125C					INRC
1N1687	2	Si	600	600			35	125C					INRC
1N1745	1	Si	1500	1500	300	15	30ma	150A		25	1500	25A	INRC
1N1746	1	Si	1500	1500	360	7.5	36ma	150A		25	1500	25A	INRC
1N1747	1	Si	1800	1800	270	18	27ma	150A		25	1800	25A	INRC
1N1748	1	Si	1800	1800	330	9.0	33ma	150A		25	1800	25A	INRC
1N1749	1	Si	2400	2400	220	24	22ma	150A		25	2400	25A	INRC
1N1750	1	Si	2400	2400	270	12	27ma	150A		25	2400	25A	INRC
1N1751	1	Si	3600	3600	290	27	29ma	150A		25	3600	25A	INRC
1N1752	1	Si	3600	3600	280	18	28ma	150A		25	3600	25A	INRC
1N1753	1	Si	4800	4800	230	36	23ma	150A		25	4800	25A	INRC
1N1754	1	Si	4800	4800	220	24	22ma	150A		25	4800	25A	INRC
1N1755	1	Si	6000	6000	210	45	21ma	150A		25	6000	25A	INRC
1N1756	1	Si	6000	6000	280	30	28ma	150A		25	6000	25A	INRC
1N1757	1	Si	7200	7200	250	54	24ma	150A		25	7200	25A	INRC
1N1758	1	Si	7200	7200	230	36	23ma	150A		25	7200	25A	INRC
1N1759	1	Si	8000	8000	220	60	22ma	150A		25	8000	25A	INRC
1N1760	1	Si	12K	12K	220	60	22ma	150A		25	12K	25A	INRC
1N1761	1	Si	14K	14K	240	52	24ma	150A		25	14K	25A	INRC
1N1762	1	Si	16K	16K	220	60	22ma	150A		25	16K	25A	INRC
1N2069	1	Si	200	200			.50	100		200Ø	200	100	TI
1N2070	1	Si	400	400			.50	100		200Ø	400	100	TI
1N2071	1	Si	600	600			.50	100		200Ø	600	100	TI
1N2116	2	Si	400		500	1.3	.50	100A		700	400	100	INRC
1T22G	1	Ge	75	60	5	1.0	50ma	25		30	10	25	SONY
1T23G	1	Ge	30	20	25	1.0	25ma	25		50	10	25	SONY
1T51	1	Ge		25	1.2	.115	.10	25		300	25	25	SONY
1T52	1	Ge		25	1.2	.135	.10	25		300	25	25	SONY
10H	2	Si	100	70			.75	55	.50	1000	100	25	SAR
10J1	2	Si	100	70			1.5	55	.50	5000	100	25	SAR
10J2	2	Si	100	70			10	55	.50	5000	100	25	SAR
10LA	2	Si	100	70			1.5	55	.50	5000	100	25	SAR
20H	2	Si	200	140			.75	55	.50	1000	200	25	SAR
20J1	2	Si	200	140			1.5	55	.50	5000	200	25	SAR
20J2	2	Si	200	140			10	55	.50	5000	200	25	SAR
20LA	2	Si	200	140			1.5	55	.50	5000	200	25	SAR
30H	2	Si	300	210			.75	55	.50	1000	300	25	SAR

CHARACTERISTICS CHART of DIODES and RECTIFIERS

TYPE NO.	USE (See Code Below)	MAT	PIV (volts)	MAX. CONT. WORK. VOLT. (volts)	Min. Forward Current @ 25°C I_f (mA)	@ E_f (volts)	MAX. D.C. OUTPUT CURRENT[4] (amps)	@ T (°C)	MAX. FULL LOAD VOLT. DROP[4] (volts)	Max. Rev. Current I_b (uA)	@ E_b (volts)	@ T (°C)	MFR. (See code at start of charts)
30J1	2	S1	300	210			1.5	55	.50	2500	300	25	SAR
30J2	2	S1	300	210			10	55	.50	2500	300	25	SAR
30LA	2	S1	300	210			1.5	55	.50	2500	300	25	SAR
40H	2	S1	400	280			.75	55	.50	1000	400	25	SAR
40J2	2	S1	400	280			10	55	.50	2500	400	25	SAR
40LA	2	S1	400	280			1.5	55	.50	2500	400	25	SAR
50H	2	S1	500	350			.75	55	.50	1000	500	25	SAR
60H	2	S1	600	420			.75	55	.50	1000	600	25	SAR
327E†	2	S1	250	250	80A	1.0	240	100	.60	50ma	250	25	WEST
327G†	2	S1	350	350	80A	1.0	240	100	.60	50ma	350	25	WEST-6
328E†	2	S1	250	250	80A	1.0	240	100	.60	50ma	250	25	WEST-6
328G†	2	S1	350	350	80A	1.0	240	100	.60	50ma	350	25	WEST-6
329E†	2	S1	250	250	52A	1.0	160	100	.60	40ma	250	25	WEST-6
329G†	2	S1	350	350	52A	1.0	160	100	.60	40ma	350	25	WEST-6
339E†	2	S1	250	250	80A	1.0	240	100	.60	50ma	250	25	WEST-6
339G†	2	S1	350	350	80A	1.0	240	100	.60	50ma	350	25	WEST-6
AG0512	2	S1	50	50			12	150	1.5	1000	50	150	GIC
AG1012	2	S1	100	100			12	150	1.5	1000	100	150	GIC
AG1512	2	S1	150	150			12	150	1.5	1000	150	150	GIC
AG2012	2	S1	200	200			12	150	1.5	1000	200	150	GIC
AG2512	2	S1	250	250			12	150	1.5	1000	250	150	GIC
AG3012	2	S1	300	300			12	150	1.5	1000	300	150	GIC
AG3512	2	S1	350	350			12	150	1.5	1000	350	150	GIC
AG4012	2	S1	400	400			12	150	1.5	1000	400	150	GIC
AG5012	2	S1	500	500			12	150	1.5	1000	500	150	GIC
AG6012	2	S1	600	600			12	150	1.5	1000	600	150	GIC
BY401	1Ø	S1	50				6.0	120	1.5	500	50	150	BRA
BY402	1Ø	S1	100				6.0	120	1.5	500	100	150	BRA
BY403	1Ø	S1	200				6.0	120	1.5	500	200	150	BRA
BY404	1Ø	S1	300				6.0	120	1.5	500	300	150	BRA
BY405	1Ø	S1	400				6.0	120	1.5	500	400	150	BRA
BY406	1Ø	S1	500				6.0	120	1.5	500	500	150	BRA
BY407	1Ø	S1	600				6.0	120	1.5	500	600	150	BRA
BY411	3Ø	S1	50				6.0	120	1.5	5.0	50	25	BRA
BY412	3Ø	S1	100				6.0	120	1.5	5.0	100	25	BRA
BY413	3Ø	S1	200				6.0	120	1.5	5.0	200	25	BRA
BY414	3Ø	S1	300				6.0	120	1.5	5.0	300	25	BRA
BY415	3Ø	S1	400				6.0	120	1.5	5.0	400	25	BRA
BY416	3Ø	S1	500				6.0	120	1.5	5.0	500	25	BRA
BY417	3Ø	S1	600				6.0	120	1.5	5.0	600	25	BRA
BY701	1	S1	50				6.0	120	1.5	500	50	150	BRA
BY702	1	S1	100				6.0	120	1.5	500	100	150	BRA
BY703	1	S1	200				6.0	120	1.5	500	200	150	BRA
BY704	1	S1	300				6.0	120	1.5	500	300	150	BRA
BY705	1	S1	400				6.0	120	1.5	500	400	150	BRA
BY706	1	S1	500				6.0	120	1.5	500	500	150	BRA
BY707	1	S1	600				6.0	120	1.5	500	600	150	BRA
BY711	3	S1	50				6.0	120	1.5	500	50	150	BRA
BY712	3	S1	100				6.0	120	1.5	500	100	150	BRA
BY713	3	S1	200				6.0	120	1.5	500	200	150	BRA
BY714	3	S1	300				6.0	120	1.5	500	300	150	BRA
BY715	3	S1	400				6.0	120	1.5	500	400	150	BRA
BY716	3	S1	500				6.0	120	1.5	500	500	150	BRA
BY717	3	S1	600				6.0	120	1.5	500	600	150	BRA
E50	2	S1	50	50			.50	100A	.50	500		100	MAL
E100	2	S1	100	100			.50	100A	.50	500		100	MAL
E200	2	S1	200	200			.50	100A	.50	500		100	MAL
E300	2	S1	300	300			.50	100A	.50	500		100	MAL
E400	2	S1	400	400			.50	100A	.50	500		100	MAL
E500	2	S1	500	500			.50	100A	.50	500		100	MAL

NOTATIONS

Under Use

1. General Purpose
2. Power Rectifier
3. Magnetic Amplifier

Ø Insulated Base

Other

4 For half wave resistive load average over 1 cycle

Under Reverse Current

⊠ Dynamic

Under Mfr.

6. Available in stack form from that manufacturer

Following any temperature reading, these symbols apply

A — Ambient
C — Case
J — Junction
S — Storage
△ — Inlet Temperature of Coolant

Type No.

† — Revised Data

Manufacturers should be contacted for value and test condition for surge current and maximum peak recurrent current

CHARACTERISTICS CHART of DIODES and RECTIFIERS

TYPE NO.	USE (See Code Below)	MAT	PIV (volts)	MAX. CONT. WORK. VOLT. (volts)	Min. Forward Current @ 25°C I_f (mA)	@ E_f (volts)	MAX. D.C. OUTPUT CURRENT[4] (amps)	@ T (°C)	MAX. FULL LOAD VOLT. DROP[4] (volts)	Max. Rev. Current I_b (uA)	@ E_b (volts)	@ T (°C)	MFR. (See code at start of charts)
E600	2	Si	600	600			.50	100A	.50	500		100	MAL
F2	2	Si	200	140			.75	55	.50	1000	200	25	SAR
F4	2	Si	400	280			.75	55	.50	1000	400	25	SAR
F6	2	Si	600	420			.75	55	.50	1000	600	25	SAR
HB1	1	Si	6.8		17	1.0	85ma	25		5.0	3.5	25	HSD
HB2	1	Si	18		5.0	1.0	50ma	25		5.0	10	25	HSD
HB3	1	Si	36		2.7	1.0	30ma	25		10	20	25	HSD
HB4	1	Si	75		.90	1.0	17ma	25		20	39	25	HSD
HB5	1	Si	150		3.0	4.0	12ma	25		40	82	25	HSD
HB6	1	Si	270		1.5	4.0	9.0ma	25		75	150	25	HSD
LD123	1	Ge	35	20	100	1.0	75ma	25A		70	20	25A	CBS
LD125	1	Ge	75	60	10	1.0	30ma	25A		500	50	25A	CBS
LD130	1	Ge	60	50	200	1.0	80ma	25A		50	50	25A	CBS
LD134	1	Ge	40	10	10	.45	70ma	25A		60	10	65A	CBS
LD141	1	Ge	80	60	20	1.0	30ma	25A		100	10	25A	CBS
LD142	1	Ge	110	100	200	1.0	80ma	25A		500	100	25A	CBS
LD143	1	Ge	75	60	40	1.0	30ma	25A		100	50	25A	CBS
PA305	2	Si	50	50			.30	100A	1.5	500	50	100A	GIC
PA310	2	Si	100	100			.30	100A	1.5	500	100	100A	GIC
PA315	2	Si	150	150			.30	100A	1.5	500	150	100A	GIC
PA320	2	Si	200	200			.30	100A	1.5	500	200	100A	GIC
PA325	2	Si	250	250			.30	100A	1.5	500	250	100A	GIC
PA330	2	Si	300	300			.30	100A	1.5	500	300	100A	GIC
PA340	2	Si	400	400			.30	100A	1.5	500	400	100A	GIC
PA350	2	Si	500	500			.30	100A	1.5	500	500	100A	GIC
PA360	2	Si	600	600			.30	100A	1.5	500	600	100A	GIC
RS50A	2	Si	50	50			5.0	100A	1.3	750	50	100	STCB
RS51A	2	Si	100	100			5.0	100A	1.3	750	100	100	STCB
RS52A	2	Si	150	150			5.0	100A	1.3	750	150	100	STCB
RS53A	2	Si	200	200			5.0	100A	1.3	750	200	100	STCB
RS54A	2	Si	300	300			5.0	100A	1.3	750	300	100	STCB
RS55A	2	Si	400	400			5.0	100A	1.3	750	400	100	STCB
RS80	2	Si	50				100	100C	1.2	25ma	50	25	STCB
RS81	2	Si	100				100	100C	1.2	25ma	100	25	STCB
RS82	2	Si	150				100	100C	1.2	25ma	150	25	STCB
RS83	2	Si	200				100	100C	1.2	25ma	200	25	STCB
RS84	2	Si	300				100	100C	1.2	25ma	300	25	STCB
SX631	3	Si	100	100	1000	1.5	.75	100	1.0	20	100	100	GECB-6
SX632	3	Si	250	250	1000	1.5	.75	100	1.0	20	250	100	GECB-6
SX633	3	Si	400	400	1000	1.5	.75	100	1.0	20	400	100	GECB-6
SX645	3	Si	400	400	100	1.5	.19	35	1.0	.07	400	25	GECB
T50	1	Si	50	50			.50	85A	.50	250		85	MAL
T100	1	Si	100	100			.50	85A	.50	250		85	MAL
T200	1	Si	200	200			.50	85A	.50	250		85	MAL
T300	1	Si	300	300			.50	85A	.50	250		85	MAL
T400	1	Si	400	400			.50	85A	.50	250		85	MAL
T500	1	Si	500	500			.50	85A	.50	250		85	MAL
T600	1	Si	600	600			.50	85A	.50	250		85	MAL
VA710D	2	Ge	100	100			120	35△	.50	100ma⍁	100	65J	EEVB
VA710E	2	Ge	80	80			80	45△	.50	100ma⍁	80	65J	EEVB
VA710F	2	Ge	60	60			40	55△	.50	100ma⍁	60	65J	EEVB
VA710G	2	Ge	40	40			40	55△	.50	100ma⍁	40	65J	EEVB
VA713D	2	Ge	100	100			13	35A	.50	50ma⍁	100	65J	EEVB
VA719D	2	Ge	100	100			20	35A	.50	60ma⍁	100	65J	EEVB-6
VA719E	2	Ge	80	80			13	45A	.50	60ma⍁	80	65J	EEVB-6
VA719F	2	Ge	60	60			6.5	55A	.50	60ma⍁	60	65J	EEVB-6
VA719G	2	Ge	40	40			6.5	55A	.50	60ma⍁	40	65J	EEVB-6
VAW722D	2	Ge	100	100			240	35△	.50	100ma⍁	100	65J	EEVB
VAW722E	2	Ge	80	80			160	45△	.50	100ma⍁	80	65J	EEVB
VAW722F	2	Ge	60	60			80	55△	.50	100ma⍁	60	65J	EEVB
VAW722G	2	Ge	40	40			80	55△	.50	100ma⍁	40	65J	EEVB

NOTATIONS

Under Use

1. General Purpose
2. Power Rectifier
3. Magnetic Amplifier

Ø Insulated Base

Other

4. For half wave resistive load average over 1 cycle

Under Reverse Current

⍁ Dynamic

Under Mfr.

6. Available in stack form from that manufacturer

Following any temperature reading these symbols apply

A — Ambient
C — Case
J — Junction
S — Storage
△ — Inlet Temperature of Coolant

Type No.

† — Revised Data

Manufacturers should be contacted for value and test condition for surge current and maximum peak recurrent current.

SEMICONDUCTOR & SOLID-STATE BIBLIOGRAPHY

TITLE	PUBLICATION	CONDENSED SUMMARY	AUTHORS
Silicon Transistor Performance in a Chopper	Applications and Industry (AIEE) 7/58	Methods of obtaining large signal behavior parameters. The series shunt chopper is limited to "low" signal impedance applications.	J. Giorgis C. C. Thompson
Low-Noise Amplifier for High Frequencies Uses New Semiconductor Diode	Bell Labs Record 7/58	Discussion on history and basic properties and applications of the "varactor" diode.	
Electrical Protection for Transistorized Equipment	Bell Labs Record 7/58	The use of a small semiconductor diode to protect the transistor represents a new protection art for telephone systems.	J. W. Phelps
The Electrical Conductivity of Manganese Arsenide and Antimonide	Canadian Journal of Physics 8/58	New measurements are reported as part of a program of relating electronic and crystal structure of compounds to their electrical properties.	G. Fischer W. B. Pearson
Improving Performance of Flat Armature Torque Motors	Control Engineering 8/58	Special techniques and drive circuits include transistorized version of torque-motor power supply.	R. D. Atchley
High Input Impedance Transistor Amplifier	Electronic Design 8/6/58	Input impedance from 50 to 100 megohms can be obtained by using cascaded emitter-follower stages.	G. F. Montgomery
Design Considerations for Class B Complementary Symmetry Audio Amplifiers	Electronic Design 8/6/58	Analysis of two basic circuits. Discussion of circuit and transistor parameters, determination of resistances and capacitance values.	C. F. Wheatly
Transistorized High Frequency Chopper Design	Electronic Design 8/6/58	High frequency chopping technique balances out unsymmetrical transistor switch impedances and undesirable carrier leakage.	Rob Roy
Designing Transistor Circuits-Combinational Logic	Electronic Equipment Engineering 8/58	Fundamentals of combinational logic are developed for a transistor switching circuit.	R. B. Hurley
Increased Cooling for Power Transistors	Electronic Industries 8/58	Discussion of a variety of radiators tried, and a "best" unit found in keeping operating temperature at maximum power below recommended ceilings.	C. Booher
New Transistor Design—The "Mesa"	Electronic Industries 8/58	Description of *uhf* low level amplifier transistor, and an ultra high speed switching transistor.	C. H. Knowles
Transistor Unit Monitors Blood Pressure	Electronics 8/15	Transistorized excitation supply amplifier and power supply circuits employed in unit which gives a continuous indication of blood pressure.	O. Z. Roy J. R. Charbonneau
Transistors Reduce Relay Servo Size	Electronics 8/15	Description of a transistor relay servo system which illustrates the simplicity possible in design of the nonlinear type.	S. Shenfeld
Transistorized Analog Digital Converter	Electronics 8/1	Description of experimental converter designed for coding of analog data in airborne telemetering systems.	W. B. Towles
Regenerative Divider Drives Precision Clock	Electronics 8/1	Crystal controlled clock with transistor divider units employing feedback of lower sideband from a balanced modulator.	D. P. Henderson
FM Tuner Uses Four Transistors	Electronics 8/1/58	Converter uses single diffused-base transistor and one variable tuning element. *I-F* stages are reflexed.	H. Cooke
Transistor Photoflash Power Converters	Electronics 8/29	New circuit designs described can also be used for other applications where *d-c/d-c* or *d-c/a-c* power or voltage conversion is required.	H. A. Manoogian
Design of Transistor RC Amplifiers	IRE Trans. on Audio 5, 6/58	Particular emphasis is placed on operating point stabilization and its relation to such factors as gain, battery drain and distortion.	R. P. Murray
Temperature Sensitivity of Current Gain in Power Transistors	IRE Trans. on Electron Devices 7/58	Conclusions indicate that the base resistance is the major single factor contributing to variations of current gain with temperature.	B. Reich
Physical Mechanisms Leading to Deterioration of Transistor Life	IRE Trans. on Electron Devices 7/58	Life tests on surface-barrier type transistors have been conducted at various temperatures and power levels to characterize these mechanisms.	G. C. Messenger
An Analysis of Base Resistance for Alloy Junction Transistors	IRE Trans. on Electron Devices 7/58	Base resistance is treated as a boundary value problem. Base spreading resistance is derived, as is h_{11}.	A. J. Wahl

TITLE	PUBLICATION	CONDENSED SUMMARY	AUTHORS
Characteristics, Structure, and Performance of a Diffused-Base Germanium Oscillator Transistor	IRE Trans. on Electron Devices 7/58	The methods of Lee have been used in making this *p-n-p* diffused base unit. Median 200-*mc* oscillator efficiency of 50% is obtained.	R. M. Warner, Jr. J. M. Early G. T. Loman
Germanium and Silicon Transistors by the Diffused-Meltback Process Employing Two or Three Impurities	IRE Trans. on Electron Devices 7/58	Two and three-impurity cases are analyzed. Applicability of the diffused meltback process for high-frequency devices is shown.	J. A. Lesk R. E. Gonzalez
A Wide-Range Junction Transistor Audio Oscillator	1958 IRE Wescon Conv. Record, Part 2	The oscillator circuit is analyzed and the problems of amplitude stabilization and frequency drift are studied.	M. A. Milehy
Comparisons Between Multiple Loop and Single Loop Transistor Feedback Amplifiers	1958 IRE Wescon Conv. Record, Part 2	An amplifier employing four transistors with a 1 *mc* bandwidth flat to .01 *db* and a useful (3 *db*) bandwidth of 10 *mc* is described.	E. M. Davis, Jr.
"Squarved" Input Stages for Low-Level Transistor Amplifiers	1958 IRE Wescon Conv. Record, Part 2	New circuits are given which provide stable low-voltage low-current operation, and stages with high input impedance, high voltage gain and low power dissipation.	K. Hinrichs B. B. Weekes
Techniques for Stabilizing *D-C* Transistor Amplifiers	1958 IRE Wescon Conv. Record, Part 2	The variation of parameters of transistors as a function of temperatures makes the use of these devices in precision *d-c* amplifiers somewhat of a problem	M. L. Klein
The Root Locus Design of Transistor Feedback Amplifiers	1958 IRE Wescon Conv. Record, Part 2	Examples and experimental results of this paper will indicate the ease in developing simple feedback amplifiers.	D. O. Peterson M. S. Ghause
A New Design Method for Coupling Networks, with Applications to Broadband Transistor Amplifiers and Antenna Matching	1958 IRE Wescon Conv. Record, Part 2	A simple design procedure is developed for two and three element ladders by minimizing the mean square magnitude of the error in the desired output admittance or impedance.	P. A. Ligomenides
A Parametric Amplifier Using Lower-Frequency Pumping	1958 IRE Wescon Conv. Record, Part 3	The principle of parametric amplification using lower-frequency pumping has been verified in using special zero-biased semiconductor diodes as nonlinear capacitors.	K. K. N. Chang S. Bloom
Comparison of Neutron Damage in Germanium and Silicon Transistors	1958 IRE Wescon Conv. Record, Part 3	Consideration is given to the mean time for minority carriers to traverse the base region of the structures being compared.	J. W. Easley
Voltage-Sensitive Semiconductor Capacitors	1958 IRE Wescon Conv. Record, Part 3	Theory, fabrication techniques and characteristics of voltage-sensitive semiconductor capacitors.	M. E. McMahon G. F. Straube
The Hall Effect Circulator—A Passive Transmission Device	1958 IRE Wescon Conv. Record, Part 3	Three-port non-reciprocal Hall Effect devices have been made which circulate *d-c* and *a-c* signals either in a clockwise or counterclockwise sense.	W. J. Grubbs
A Family of Diffused-Base Germanium Transistors	1958 IRE Wescon Conv. Record, Part 3	Design principles, fabrication techniques, and considerations of both long- and short-term device performance.	H. E. Talley
Millimicrosecond Diffused Silicon Computer Diodes	1958 IRE Wescon Conv. Record, Part 3	Description of device with switching time of 1 millimicrosecond, low capacitance, and low forward dynamic resistance.	J. H. Forster P. Zuk
The Design and Characteristics of a Diffused Silicon Logic Amplifier Transistor	1958 IRE Wescon Conv. Record, Part 3	The diffusion technique used in the fabrication of this transistor (2N560) provides a high degree of uniformity and ease of manufacture.	L. E. Miller
Switching Time Calculations for Diffused Base Transistors	1958 IRE Wescon Conv. Record, Part 3	Switching times of transistor circuits are derived from examining initial and final states and current flowing into the transistor during switching.	V. H. Grinich R. N. Noyce
High Power Silicon Transistors	1958 IRE Wescon Conv. Record, Part 3	Discussion of general design problems which have heretofore limited construction of these devices, and description of new devices with low internal dissipations and high power handling.	H. W. Henkels T. P. Nowalk
A Medium Power Silicon Controlled Rectifier	1958 IRE Wescon Conv. Record, Part 3	Electrical characteristics and ratings of a three-terminal silicon *p-n-p-n* device with characteristics similar to a thyratron.	D. K. Bisson
PNπN Switches	1958 IRE Wescon Conv. Record, Part 3	A new mechanism, that of reduced transit times through base layers due to conductivity modulation, is discussed.	J. A. Hoerni R. N. Noyce

TITLE	PUBLICATION	CONDENSED SUMMARY	AUTHORS
Masers and Parametric Amplifiers	1958 IRE Wescon Conv. Record, Part 3	Summary of basic principles and methods, and state of the art.	H. Heffner
A Transistorized, All-Electronic Cosine/Sine Function Generator	1958 IRE Wescon Conv. Record, Part 4	Description of a trigonometric function generator which provides an output voltage that is the cosine of the input voltage.	H. Schmid
GCA by Automatic Voice Data Link	1958 IRE Wescon Conv. Record, Part 4	Description of a method using transistor logic circuitry, of augmenting the operator with automatic tracking, computing, and voice data link equipment to improve the safety margins during a GCA approach.	J. J. Fling M. H. Nothman
An Emitter-Follower-Coupled, High-Speed Binary Counter	1958 IRE Wescon Conv. Record, Part 4	A binary counter capable of counting rates of 50 *mc* can be constructed using surface barrier transistors.	I. Horn
Development of a Transistorized Voltage Controllable Frequency Source	1958 IRE Wescon Conv. Record, Part 5	A method of approach to the design of a stable frequency source multivibrator is given.	W. E. Wilke W. B. Sander
Broadband Radio Interference Generated by Airborne Electronic Device	1958 IRE Wescon Conv. Record, Part 5	Interference voltages were found to be directly associated with reverse recovery transients in the diodes.	J. C. Sinn
Transistor Airborne PDM System	1958 IRE Wescon Conv. Record, Part 5	A pulse duration modulation telemetry system is described. Solid state devices are used in various sections.	W. P. Klemens
Transistorized Decade Counter	1958 IRE Wescon Conv. Record, Part 6	Description of an exceptionally reliable and versatile transistor counter circuit.	A. Szerlip
A. D. C. Reference Voltage	1958 IRE Wescon Conv. Record, Part 6	Circuit considerations, reference device (zener diode), amplifier design and analysis of system for purpose of obtaining a high degree of regulation.	K. Worcester
Analysis of Junction-Transistor Switching Circuits	Izvestia V.U.Z. No. 1: 95-104 Jan-Feb 1958 (Abs. Trans: Elec. Exp.) 6/58	Detailed treatment of V/A characteristics for a monostable switching circuit, a bistable circuit, amplitude and duration of pulses, and selecting emitter resistance.	V. V. Chervetsov
Work Function and Sorption Properties of Silicon Crystals	Jl. of Applied Physics 8/58	Work functions have been obtained by measuring the contact potential differences between the crystals and a gold reference.	J. A. Dillon H. E. Farnsworth
Application of the Ion Bombardment Cleaning Method of Titanium, Germanium, Silicon, and Nickel as Determined at Low-energy Electron Diffraction	Jl. of Applied Physics 8/58	Conditions and precautions necessary for the production of clean surfaces are described. It has been shown that contamination approximately one-half monolayer does not occur under the conditions which were obtained, and that the surfaces are atomically clean.	H. E. Farnsworth R. E. Schlier T. H. George R. M. Burger
Ohmic Probe Contacts to CdS Crystals	Jl. of Applied Physics 8/58	Wire probe contacts are found to be diodic upon first touching CdS but can be permanently changed from diodic to ohmic by the passage of an electric pulse.	Y. T. Sihvonen D. R. Boyd
Meissner Effect and Gauge Invariance	Physical Review 8/1/58	It is shown from a manifestly gauge invariant Hamiltonian that the Meissner effect can follow from an energy-gap model of superconductivity.	G. Rickayzen
Piezoresistance in Heavily Doped *n*-Type Germanium	Physical Review 8/1/58	Piezoresistance has been measured as a function of temperature in *n*-type germanium specimens with donor concentrations between 6×10^{15} cm^{-3} and 3×10^{19} cm^{-3}.	M. Pollak
Thermoelectric Power of Dilute Indium-Lead and Indium-Thallium Alloys	Physical Review 8/1/58	This investigation is extended to include some 22 indium-lead alloys and 13 indium-thallium alloys.	W. J. Tomasch J. R. Reitz
Normal Modes of Germanium by Neutron Spectrometry	Physical Review 8/1/58	The frequency wave-number relations of the lattice vibrations in germanium which propagate in the symmetric (100) and (111) directions have been obtained.	B. N. Brockhouse P. K. Iyengar
Seebech Effect Fluctuations in Germanium	Physical Review 8/15/58	The Seebech noise power spectrum varies as reciprocal frequency and may be quantitatively predicted from current-noise measurements.	J. J. Brophy
Mobility of Electrons and Holes in PbS, PbSe and PbTe, Between Room Temperature and 4.2° K.	Physical Review 8/15/58	Hall coefficient and resistivity measurements made on 29 single crystals indicate that almost all samples had extrinsic carrier concentrations of the order of 10^{18} per cm^3.	R. S. Allgaier

PATENT REVIEW*

Of Semiconductor Devices, Fabrication Techniques and Processes, and Circuits and Applications Sept. 9, 1952 to July 28, 1953

Compiled by SIDNEY MARSHALL

The abstracts appearing in this issue cover the inventions relevant to semiconductors from September 9, 1952 to July 28, 1953. In subsequent issues, patents issued from July 28, 1953 to date will be presented in a similar manner. After bringing these abstracts up to date, PATENT REVIEW will appear every three months, the treatment given to each item being more detailed.

September 9, 1952

2,610,244 Keyboard Operated Translating Circuit—W. H. Burkhart, H. M. Fleming, Jr.; Assignee: Monroe Calculating Machine Company; A circuit comprising an output line, a resistor connecting said line with a source of potential, a plurality of input lines, a series of diodes between the input and output lines, and a series of keyboard switches.

September 30, 1952

2,612,550 Voltage Level Selector Circuit;—G. T. Jacobi; Asignee: General Electric Company: A voltage level selector circuit comprising n conductors, a resistor in series with each conductor, voltage dividing means, and n pairs of unilateral impedance devices.

2,612,567 Transconductor Employing Field-Controlled Semiconductor;—O. Stuetzer; Assignee: None; A transconductive device comprising a thin-walled insulating tube, a pile in said tube of alternate metal particles and semiconductive discs. The device provides the unilateral transconductance or mutual conductance of a three electrode vacuum tube, but does not require an envelope or a thermionic emitter.

October 14, 1952

2,614,140 Trigger Circuit;—J. G. Kreer Jr.; Assignee: Bell Telephone Laboratories; In a trigger circuit, two small passive type negative resistance units are utilized in a double-stability arrangement for the production of suitably shaped discontinuous wave forms.

2,614,141 Counting Circuit;—J. O. Edson; Assignee: Bell Telephone Laboratories; An electrical counter-circuit comprising in combination a plurality of variable resistance elements, crystal diodes and a potential source.

2,614,142 Trigger Circuit;—J. O. Edson; Assignee: Bell Telephone Laboratories; A circuit utilizing two-terminal negative resistance units and having two conditions of stability which may be triggered or changed from one to the other by successive pulses of the same polarity.

October 28, 1952

2,615,857 Polyethylene - Polyisobutylene Composition;—W. J. Clarke; Assignee: Bell Telephone Laboratories; A composition consisting of a gel of about 5% to 35% polyethylene and the remainder a viscous liquid polyisobutylene, said composition applicable for use in the construction of germanium point-contact devices.

2,615,965 Crystal Amplifier Device;—S. F. Amico; Assignee: Sylvania Electric Products Inc.; A wedge-shaped semiconductor crystal and two metal strip contacts engaging the edge of the wedge-shaped crystal to effect two point-contacts.

2,615,966 Alloys and Rectifiers Made Thereof;—K. Lark-Horovitz, R. M. Whaley; Assignee: Purdue Research Foundation; A point-contact semiconductor device composed of an alloy of 99% pure germanium and at least one of the elements from group III of the periodic system.

2,616,074 Apparatus for Utilizing The Hall Effect;—H. J. McCreary; Assignee: Automatic Electric Laboratories, Inc.; A device designed to greatly change the resistance in the Hall circuit so as to make the device of practical value as an amplifier in an electronic circuit.

November 11, 1952

2,617,865 Semiconductor Amplifier and Electrode Structure Therefor;—J. Bardeen, W. H. Brattain; Assignee: Bell Telephone Laboratories; A circuit element comprised of a body of semiconducting material, one electrode making contact with said body over a large area, and at least two other electrodes making contact with the body over a narrow line the area of which is small compared to the first electrode.

November 18, 1952

2,618,690 Transconductor Employing Line Type Field Controlled Semiconductor;—O. M. Stuetzer; Assignee: None; A transductive device having a fine-wire electrode making line contact with a semiconductive body, an electrical-field-controlling electrode separated from the semiconductor and the first electrode by a dielectric.

2,618,691 Point-Contact Semiresistor Assembly;—B. Bethge, H. Welker; Assignee: Societe Anonyme Compagnie des Freins et Signaux Westinghouse; The device is designed to provide an improved transistor construction in which two point electrodes make a high resistance point contact with closely spaced but distinct points of a semiconductive surface.

2,618,692 Locator Device for Selenium Rectifiers;—G. J. Eannarino; Assignee; Sarkes Tarzian Inc.; A locator comprising a centrally apertured plate having rearwardly extending washer edge-engaging ears.

November 25, 1952

2,619,602 Apparatus For the Supply of High-Voltage Unidirectional Currents From A Relatively Low-Voltage Alternating Current Source;—A. H. Walker, L. H. Peter; Assignee: Westinghouse Brake and Signal Co. Ltd.; The circuit provides a center-tap transformer and a rectifying network.

2,619,414 Surface Treatment of Germanium Circuit Elements;—R. D. Heidenreich; Assignee: Bell Telephone Laboratories; Treating a semiconductive surface with a mixture including acetic acid, nitric acid, hydrofluoric acid, and bromine, improves its electrical characteristics, increases its reverse resistance, and improves its photosensitivity.

December 2, 1952

2,620,384 Selenium and Like Rectifier Stack; Sarkes Tarzian; In a rectifier stack, a radially corrugated metallic and resilient washer placed at opposite sides thereof, a lock washer at each end of the stack, and at least one rectifying plate.

2,620,448 Transistor Trigger Circuits;—R. L. Wallace; Assignee: Bell Telephone Laboratories; Apparatus whose performance is dual to a vacuum tube circuit. The circuit utilizes a pair of three terminal transistors, and an impedance element common to both transistors.

December 16, 1952

2,622,117 Photovoltaic Device;—S. Benzer; Assignee: Purdue Research Foundation; A semiconducting body exhibiting a high inverse voltage and having on its surface a light-transmitting metal film.

2,622,211 Stabilized Transistor Trigger Circuit;—R. L. Trent; Assignee: Bell Telephone Laboratories; The circuit is comprised of a three terminal transistor, a point of reference potential, and three circuits connecting the base emitter and collector to the reference point.

2,622,212 Bistable Circuit;—A. E. Anderson, R. L. Trent; Assignee: Bell Telephone Laboratories; A bistable circuit comprising a pair of cross-coupled trigger circuits each of which include a transistor, said circuits having two stable operating conditions, one characterized by positive emitter current, and the other by negative emitter current.

2,622,213 Transistor Circuit For Pulse Amplifier Delay and The Like;—J. R. Harris; Assignee: Bell Telephone Laboratories; The device is designed to deliver a strong voltage step of the desired po-

*Source: Official Gazette, United States Patent Office. Also, Specifications and Drawings of Patents Issued from the U. S. Patent Office.

larity following a predetermined delay.

December 23, 1952
2,623,102 Circuit Element Utilizing Semiconductive Materials;—W. Shockley; A device comprising a body of semiconductive material containing significant impurities and including a plurality of zones of alternately opposite conductivity types.
2,623,103 Semiconductor Signal Translating Device;—R. J. Kircher; Assignee; Bell Telephone Laboratories; A semiconductive device comprised of two zones of one conductivity-type separated by a thin zone of the opposite conductivity-type.
2,623,104 Rectifier Assembly;—J. H. Hall; Assignee: Fansteel Metallurgical Corp.; A rectifier stack assembly having the plates mounted on a tubular insulating member, means for positively locking the plates in position, said plates being connected in such a manner as to form a predetermined rectifying circuit.
2,623,105 Semiconductor Translating Device Having Controlled Gain;—W. Shockley, M. Sparks; Assignee: Bell Telephone Laboratories; A signal translating device comprising a body of semiconductive material having a p-n junction therein, emitter, collector, and base connections, and a zone of substantially intrinsic conductivity between the junction and the collector.

December 30, 1952
2,624,033 Series Connected Cells with Individual Rectifier Units;—M. C. Jacquier; Assignee: Societe des Accumulateurs Fixes et de Traction; A battery comprising a plurality of cells, connected in series with a dry-type rectifier shunting each cell, each rectifier being connected so that current flows from the negative to the positive terminal of the corresponding cell.

January 13, 1953
2,625,592 Asymmetrical Conductive Element—R. Sueur, H. Welker, H. Matare, B. Bethge. Assignee: Societe Anonyme dite: Compagnie des Freins et Signaux Westinghouse. An asymmetrical conductive element comprising a pair of conductive supports, semiconductive contact member, and a conductive contact member.

Janary 27, 1953
2,626,985 Electrical Crystal Unit—P. E. Gates. Assignee: Sylvania Electric Products Inc. A point-contact semiconductor translator enclosed in an envelope having a metal end cap, a glass-walled portion, and a metal fitting sealed to the glass-walled portion.
2,627,039 Gating Circuits—W. H. MacWilliams, Jr. Assignee: Bell Telephone Laboratories. An amplifying gating matrix for connecting one at a time any of m input circuits to any of n output circuits, said matrix consisting of m input transistors and n output transistors and circuit means for achieving the result described above.

February 3, 1953
2,627,545 Semiconductor Device—D. R. Muss, L. P. Hunter. Assignee: Westinghouse Electric Corp. The device provides a rigid rectifying contact for use in semiconducting amplifier diodes.
2,627,575 Semiconductor Translating Device—L. A. Meacham, S. E. Michaels. Assignee: Bell Telephone Laboratories. A device consisting of a body of semiconductive material, means for injecting charge carriers of opposite polarity to those normally present in said body, a rectifying connection to said body, and means for applying voltage pulses in the reverse direction to said rectifying connection.

February 10, 1953
2,628,310 Counter Circuits—M. L. Wood. Assignee: International Business Machines Inc. A counter circuit comprising a plurality of serially arranged trigger circuits, each including a three-terminal semiconductor device.
2,628,936 Method of Forming a Point at the End of a Wire—V. J. Albano. Assignee: Bell Telephone Laboratories. A chemical method, involving etching, of sharpening a metallic member to produce a sharp pointed wire by controlling the shape of the interface between the etchant and the wire.

February 24, 1953
2,629,672 Method of Making Semiconductive Translating Devices—M. Sparks. Assignee: Bell Telephone Laboratories. The method involves dropping a globule of molten p-type germanium or silicon upon a heated body of n-type germanium or silicon in an oxygen free atomosphere, cooling the globule base unit, and heating to reconvert any initially n-type material back into n-type material.
2,629,767 Semiconductor Amplifier or Oscillator Device—H. Nelson, B. N. Slade. Assignee: Radio Corporation of America. A semiconductive body having contiguous conductive and semiconductive surface portions, a plurality of small-area electrodes connected to the semiconductive portions and placed adjacent to each other and the conductive portions.
2,629,800 Semiconductor Signal Translating Device—G. L. Pearson. Assignee: Bell Telephone Laboratories. A body of p-type germanium having on one surface an integral skin of n-type germanium of the order of 0.002 inch thick, a large-area ohmic connection to the body and an ohmic connection to the outer face of the skin.
2,629,802 Photocell Amplifier Construction —J. I. Pantchechnikoff. Assignee: Radio Corporation of America. An integral semiconductor photoresponsive and amplifier device comprising a semiconductive body embedded in an insultaing material but having one exposed surface, a metallic film covering and contacting the exposed surface, and three conductors.
2,629,833 Transistor Trigger Circuits—R. L. Trent. Assignee: Bell Telephone Laboratories. The apparatus enables one to modify the current-voltage characteristic of a negative resistance circuit to obtain desired slopes over given regions, and to equalize the positive impedances displayed by a trigger circuit when operating in any of its two or more impedance regions.
2,629,834 Gate and Trigger Circuits Employing Transistors—R. L. Trent. Assignee: Bell Telephone Laboratories. A circuit utilizing a three terminal transistor, and having means for promoting sufficient feedback from the collector-base circuit to the emitter-base circuit to produce a negative resistance region in the emitter current-voltage characteristic.
2,629,858 Transistor Amplitude Modulator —L. L. Koros. Assignee: Radio Corporation of America. An amplitude modulation system comprising a three-terminal transistor, means for applying operating potentials, a carrier wave source coupled between the emitter and the base, a modulation signal source coupled between the collector and the base, and a resonant output circuit.

March 17, 1953
2,631,356 Method of Making P-N Junctions in Semiconductor Materials—M. Sparks, G. K. Teal. Assignee: Bell Telephone Laboratories. A method that consists of melting a mass of material of one conductivity type, and growing a crystal at the rate of solidification by using a seed of the opposite conductivity type.
2,632,042 Electrical Crystal Unit—J. E. Fitchett. Assignee: Sylvania Electric Products Inc. The device consists of a glass envelope. a metal tube having one end sealed to the envelope, a pin extending through the tube and into the envelope, and a semiconductor element supported by the pin.
2,632,062 Semiconductor Transducer—H. C. Montgomery. Assignee: Bell Telephone Laboratories. An electromechanical transducer comprising a body of semiconductive material having therein an n-p junction, said device being capable of high fidelity translation of acoustic or mechanical variations into electrical signals.
2,632,146 Transistor Frequency Modulation—W. E. Kock. Assignee: Bell Telephone Laboratories. Frequency modulation apparatus comprising an elongated body of semiconductive material, a charge injecting circuit, a charge withdrawing circuit, means for establishing a longitudinal electric field within the body, and means for controlling the field and thus controlling the transit time.

March 24, 1953
2,632,872 Control Circuit—A. Warsher. Assignee: Bendix Aviation Corp. The circuit provides a means for obtaining a rate lead voltage by demodulating a varying suppressed carrier signal, and without using filter or log networks, advancing the demodulated signal in phase and then remodulating it upon another carrier.

March 31, 1953
2,633,489 Crystal Valve or Rectifier—T. H. Kinman. Assignee: General Electric Company. A point-contact rectifying device comprising a whisker assembly, a crystal assembly and support, and a glass envelope encasing the entire device.

April 7, 1953
2,634,322 Contact for Semiconductor Devices—H. B. Law. Assignee: Radio Corporation of America. A device consisting of a semiconductive body, one low-resistance contact electrode, a second and a third electrode not in contact with each other, each in the form of a conducting layer of evaporated metal on the semiconductive body.
2,634,323 High Gain Semiconductor Amplifier—J. I. Pantchechnikoff. Assignee: Radio Corporation of America. A semiconductive body, one low resistance electrode, two filamentary-conductor electrodes, and means for pressing the tips of these two electrodes individually against the semiconductor with differing contact pressures.

April 14, 1953
2,635,197 Electrical Apparatus—C. A. Routledge, A. J. Keen. Assignee: The British Tabulating Machine Company Ltd. An electrical system comprising an electromagnetic relay, a dry rectifier connected in parallel with the relay winding, said rectifier providing a undirectional low

(*Continued on page 62*)

New Products

Low Temperature Coefficient Wire

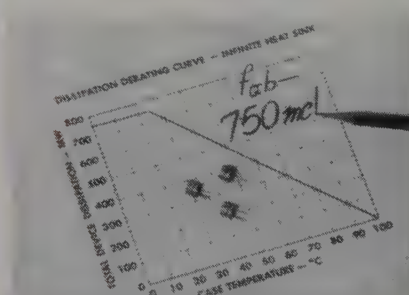
Wire made of an alloy called MOLECULOY is now available from Molecu-Wire Corp. MOLECULOY maintains its temperature resistance characteristics over temperatures ranging from extremes of minus 65° C to plus 250°, possessing a very low thermal EMF vs. Copper and is a nonmagnetic 75/20 nickel chromium alloy, modified with additions. It is available in diameters ranging from .010-inch to .0004-inch, in bare, enameled, oxidized and fabric-covered finishes.

Circle 181 on Reader Service Card

Diffused-Base Germanium Transistors

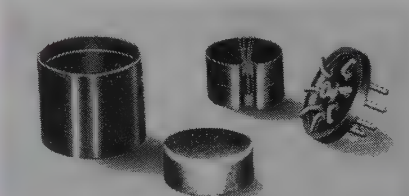
The availability of a new series of germanium high frequency, diffused-base "mesa" transistors featuring alpha cutoff frequencies up to 750 megacycles and power dissipations of 750 milliwatts was announced by Texas Instruments. The high reliability of this new series, 2N1141, 2N1142 and 2N1143, coupled with these new highs in power and frequency performance provides significant advances to the transistorization of military missile and other airborne military circuitry. Highlighting minimum current gains of 12, 10 and 8 db at 100 megacycles, these new P-N-P devices operate at junction temperatures up to 100° C with 750 milliwatts power dissipation at 25° C case temperature.

Circle 180 on Reader Service Card



All-Epoxy Encapsulation System

The E-Pak System, developed by Epoxy Products, reduces both assembly time and reject rates on electronic components. It consists of an all-epoxy header with embedded lead wires, a cured epoxy shell and a premetered epoxy pellet. All three parts of the system may be custom-made for particular requirements. An all-epoxy cover replaces the conventional glass-to-metal header in this type of packaging. After the component is soldered to the cover, a premetered epoxy pellet is



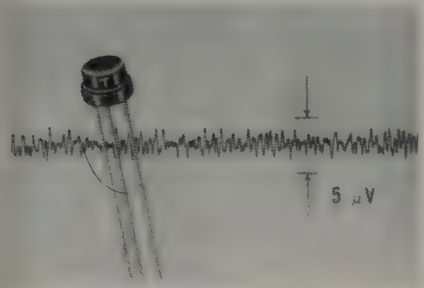
dropped into the cured epoxy shell along with the component-cover combination. The entire package is then heated; the pellet automatically melts, gels, and cures, embedding the component and sealing the cover. The result is a solid, chemically-inert seal from within.

Circle 153 on Reader Service Card

Low Noise Transistors

Two Transitron NPN silicon transistors feature noise levels comparable to the best available vacuum tubes. Specified at typically high noise frequencies (from audio down to one cycle per second), the ST1050 has equivalent input noise voltage of about one microvolt RMS when used with low source impedances. The ST1051, offers low noise current of 0.05 millimicroamps RMS and is designed for use with high source impedances. Write for Bulletin TE-1353.

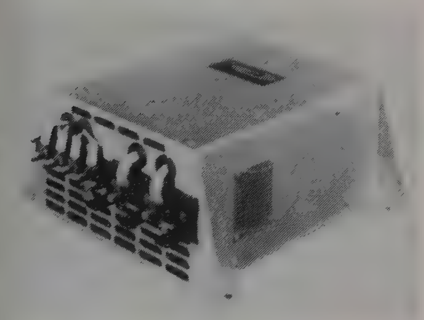
Circle 168 on Reader Service Card



Transistorized Converter

A new transistorized converter Model W-1328 has been announced by Electro-solids Corp. The transformer-rectifier unit is constructed of PN-junction type diodes to effect a weight saving that results in a 200-ampere unit weighing only 17 pounds. The 28-volt unit accepts three phase input power at 400 cycles per second, 115/200 volts. Uses solid-state components throughout.

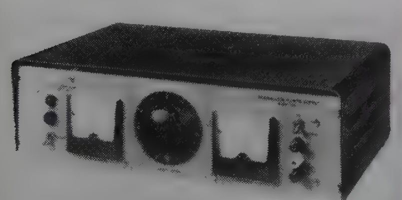
Circle 169 on Reader Service Card



Transistorized Power Supplies

Armour Electronics announces availability of its T-200 Series, Transistorized Power Supplies. Eight standard models provide output ranges suitable for both transistor and vacuum tube circuitry. The T-200 supplies provide 0.1% or 30 MV line or load regulation, 50 microsecond recovery time, 0.2% 24 hour stability and short circuit proof design. Forced air cooling in all models provides excellent heat dissipation and insures reliable operation under severe conditions.

Circle 164 on Reader Service Card



Test Chambers

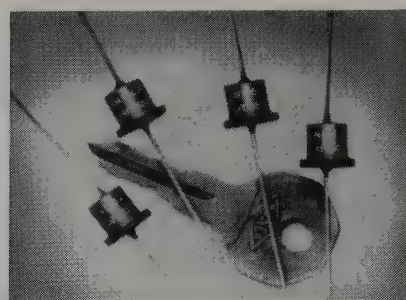
Itemco, Inc. has introduced a Standard line of Environmental Test Chambers; the TempLine Series, featuring high and low temperatures, controlled humidity ranges and altitude, available in 3 sizes. Include stainless steel interiors, are fully self-contained, functionally designed, and engineered to satisfy all the requirements of MIL Specifications. Many special variations are available to meet specific needs.

Circle 174 on Reader Service Card

Silicon Rectifier

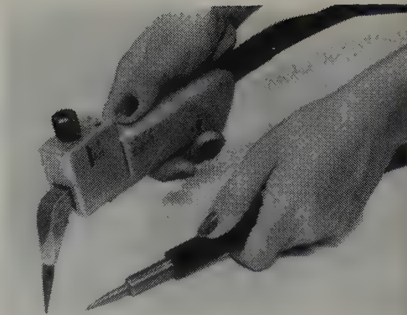
The Raytheon Semiconductor Division announces the addition of types 1N1763 and 1N1764 to its line of silicon rectifiers. These new types of the wire-in construction are small in size, suitable for high temperatures and usable in a variety of commercial and entertainment equipments. 1N1763 has a Peak Inverse Voltage rating of 400 volts and a DC load current rating of 500 milliamperes at 25°C. The ratings for 1N1764 are identical except for a 500 volt peak inverse. Both types have a maximum reverse current of 100 microamperes at the peak inverse voltage.

Circle 156 on Reader Service Card



Heavy-Duty Pressure Probe

A pressure-sensitive resistance welding probe, designed for welding thermocouples, is available from Weldmatic Division of Unitek Corp. The handpiece consists of a welding lead, complete with pressure-sensing mechanism, and a separate ground lead. The probe fires at a



preset pressure from 1 to 25 pounds, producing a heavy current for millisecond durations. It may also be used to weld honeycomb sections and special electrical and electronic assemblies, and is especially valuable in any application where only one side of the workpiece is accessible, or where it is impractical to bring materials together for a standard welding head. The separate grounding probe enables completion of the electrical circuit entirely from the top.

Circle 172 on Reader Service Card

Tantalum Capacitors

A series of rectangular case tantalum electrolytic capacitors intended for applications which require large amounts of capacitance at low voltage under wide temperature extremes from —55°C to +125°C, as well as under conditions of severe vibration and shock, has been announced by Sprague Electric Co.

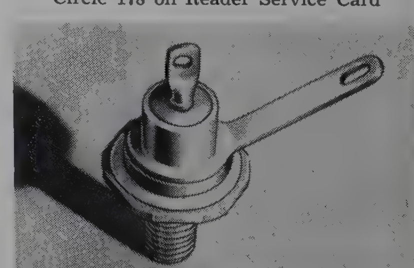
Known as Sprague Type 200D Tantapak Capacitors, they are available in five case sizes to take maximum advantage of space requirements. Write for Bulletin 3705.

Circle 161 on Reader Service Card

Insulated Base Rectifiers

Bradley Semiconductors announces their new "Redtop" insulated base silicon rectifier designed to eliminate excess hardware. Unit utilizes high alumina-content ceramic disc combining high thermal conductivity with effective electrical insulation from the heat sink. Integral 1-piece insulated base makes possible simplified more compact bridge and doubler circuit mountings.

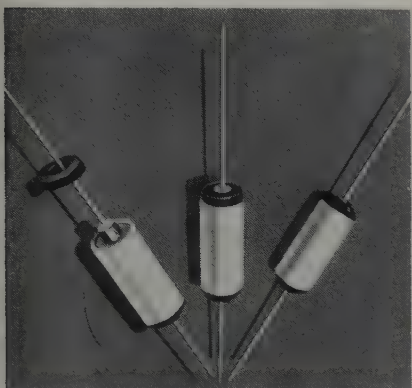
Circle 178 on Reader Service Card



Pre-Formed Epoxies

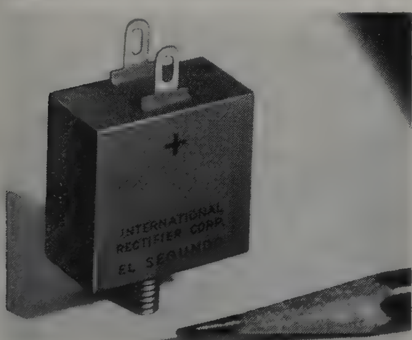
Mansol Ceramics offers the electronic component and assembly manufacturer an extensive line of pre-formed epoxies for hermetic sealing and bonding. They are pre-molded, or pre-cut, to the exact shape, and formulated to flow and cure at the customers temperature-requirment, resulting in a consistently bonded or sealed component. In addition to assembly requirements epoxies are tailored to the operating conditions of the finished product, meeting mechanical, ambient, and electrical requirements.

Circle 150 on Reader Service Card



Encapsulated Rectifier

Encapsulated to provide optimum heat dissipation, the new Type QM50 selenium rectifier can withstand high current and voltage surges to provide trouble-free circuit operation in small radio, phonograph, relay and other power supply ap-

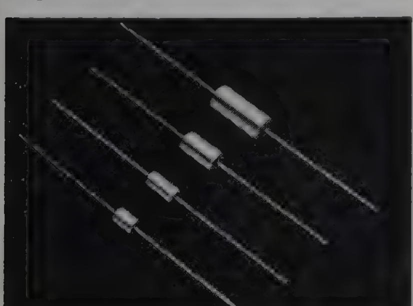


plications. Manufactured by International Rectifier Corporation, it features a rugged, phenolic-encapsulated package which completely seals rectifier cell surfaces; assures positive insulation from other chassis components. Write for Bulletin SR-164.

Circle 175 on Reader Service Card

Solid Tantalum Capacitors

Fansteel Metallurgical Corporation's subminiature STA Solid Tantalum Capacitor is now available for electronic applications requiring extremely small size, higher capacitance and extended operating temperatures. Can be supplied in ranges of .0047 to 330 mfd., from 6 to 60



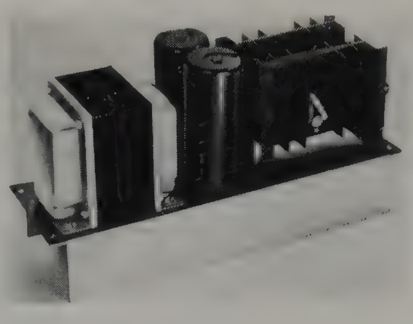
volts (WVDC)—with maximum stability and reliability at temperatures ranging from —55°C to 125°C. All are standard ratings utilizing a 20% decade, 20% tolerance system and a 10% decade, 10% tolerance system. Write for Bulletin 6.112-4.

Circle 163 on Reader Service Card

Modular Power Supplies

Dressen-Barnes announces a line of fully transistorized power supplies Models 22-111 thru 22-117 designed for use as components in original equipment. These sub-chassis units can be built into deliverable equipment. Voltage ranges from 5-7 volts at 3.0 amps., up to 27-32 volts at 1 amp. Regulation for these units, line and load combined, is 0.5%; maximum transient NL to FL is 200 MV. Short-circuit proof. Ripple: 2 MV RMS. Maximum operating temperature: 50°C. Can be operated in series to supply higher voltages, or mounted on panels for standard rack mounting if required.

Circle 162 on Reader Service Card



Switching Transistors

A series of PNP switching transistors which incorporate maximum reliability and high-temperature stability has been announced by Sylvania Electric Products Inc. Designated Types 2N404, 2N425, 2N426, 2N427 and 2N428, the new series utilizes a hermetically sealed inverted base TO-5 package which offers heat dissipation up to 150 mw at 25 degrees Centigrade. Type 2N404 has a collector to base voltage of —25 volts, a junction temperature of —65 degrees to +85 degrees C with carefully controlled leakage current. Types 2N425 thru 2N428 have —30 volts collector to base voltage, 150 mw power dissipation, and —65 to +85 junction temperature.

Circle 167 on Reader Service Card

Voltage Regulators

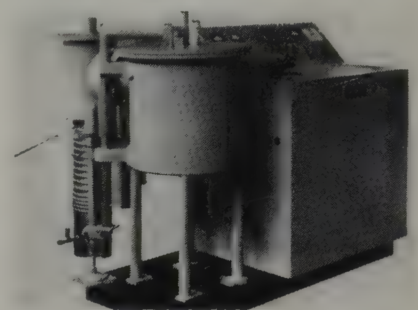
A new line of compact, heavy-duty electromechanical A.C. voltage regulators is announced by the American Rectifier Corp. Called the Selenivac, these precision units are designed for 25, 50, 60 or 400 cycle operation and provide ±1% concontrol with no waveform distortion. Input voltages may be one-phase, two-phase (3 or 4 wire) and three-phase. A switch permits either manual or automatic operation.

Circle 170 on Reader Service Card

Vacuum Furnace

The new Stokes compact cold-wall resistance-heated vacuum furnace, is capable of operating at temperatures up to 2200 deg. C. (4000 deg. F.). It is suitable for sintering powder metal parts compacted of materials with a very high melting point, such as tantalum, or for degassing components such as tungsten elements for electronic tubes, which require equally high temperatures, as well as for other heat-treating operations, either in experimental work or small-scale production.

Circle 151 on Reader Service Card



Welding Equipment

Ewald Instruments announces their WHD 4A small precise bench welding head with exceptionally low inertia. Linear motion in ball bushings. Pressure 1 to 20 lbs., adjustable on 3½" long calibrated scale. Versatile and easy to set up and to jig up. For production or laboratory welding of parts .001 to .125" thick. Also available for air operation with or without electronic hold timer. Information on other welding units available.

Circle 179 on Reader Service Card

Flat Selenium Rectifiers

New line of flat type Siemens selenium rectifiers, believed to combine the most efficient ratings in the smallest package yet developed for wide commercial use, are now in stock and available from Radio Receptor Company, Inc. (Semiconductor Division), a subsidiary of General Instrument Corporation. This type of rectifier has been in use in Europe for a number of years, but represents a new concept in the United States, and has application in both entertainment and industrial electronic equipment. Write for Bulletin 268.

Circle 154 on Reader Service Card

Hall Generators

A complete line of Hall Generators, which allow multiplication of two electrical quantities, featuring better than one percent linearity over an output range of 100,000 to 1, is announced by Device Development Corp. These units, manufactured from indium arsenide and indium antimonide, have low temperature coefficients, high accuracy and repeatability, excellent high-frequency properties, and are available with external magnetic field coils already provided, or in the form of probes for use in the customer's own magnetic circuit.

Circle 171 on Reader Service Card

Transistor Chopper

Solid State Electronics introduces Model 70 silicon transistor chopper (or modulator), designed to alternately connect and disconnect a load from a signal source. Can also be used as a demodulator to convert an a.c. signal to d.c. Encapsulated in epoxy resin, resulting in an ability to withstand shock of 500g for 11 milliseconds, 30g vibration from zero to 2000 cps, and acceleration to 700g. Operating temperature is from —55°C. to +130°C. Chopping frequency is d.c. to 100 kc or higher. The driving voltage is square wave, 5-10 volts peak to peak. Both driving source and input resistances are 600 ohms.

Circle 177 on Reader Service Card

Analytical Balance

E-H Research Laboratories announces Model 301A Automatic Analytical Balance which features 1-second measurement time and 0.2% accuracy in five automatic ranges from 30 to 3000 milligrams full scale. On any automatic range the weight of samples placed on the balance is given directly with no mechanical manipulations. Conventional difference methods may be used to extend the range to 200 grams. Features electrical mass offset allowing operator to zero the meter with a container on the balance, thus obtaining the weight of added contents directly.

Circle 173 on Reader Service Card

Switch Assemblies

A series of pushbutton switch assemblies, 1PB600, incorporating an electronic circuit to produce a single, microsecond-length pulse with each operation, has been introduced by Micro Switch. These "one-shot" switches eliminate the need of designing special pulse input circuits for high-speed electronic switching devices. The square wave pulse width is factory adjustable from .2 to 2.5 microseconds, and the amplitude from 3 to 60 volts. Both width and amplitude are independent of the speed of switch operation. No standby power is required. Write for Data Sheet 150.

Circle 176 on Reader Service Card

Silicon Rectifiers

Type TSR encapsulated silicon rectifier, developed by P. R. Mallory & Co., has a diffused junction and is designed for 85°C ambient temperature. In addition to this unit, the line includes a plug in type, Type PSR for TV sets already converted to silicon rectifiers; a top hat type, Type ESR for industrial and military applications requiring operation in severe environmental conditions; and a stud type, Type SSR, also for industrial and military applicaitons.

Circle 152 on Reader Service Card

Digital Readout

A new easily read in-line in-plane digital readout, Model SGS-101, using selective group switching, which is claimed to be a new principle in readout construction, has been developed by Electronic Equipment Div., I.D.E.A., Inc. The displayed characters are well defined and easy to read, even with high ambient light and at viewing angles up to 150°. The units consist solely of a resistor matrix and neon bulbs utilizing a printed circuit plug-in connector; other termination is available on order.

Circle 165 on Reader Service Card

Double-Diffused Rectifiers

Double diffusion processed Silicon Rectifiers in the Jetec series 1N536 through 1N540 and in the Jetec series 1N2080 through 1N2086 have been released by the Semiconductor Manufacturing Division of Columbus Electronics Corp. Hermetically sealed, axial lead top hat design, the units withstand high overload currents. Other features include 500 to 750 mA rectified current and up to 600 peak inverse volts without heat sink.

Circle 158 on Reader Service Card

Digital Logical Packages

A complete set of solid state digital logical packages produced by Packard-Bell Computer Corp. can be combined to build registers, counters and other data handling equipment, including computers. The packages include flip-flops, inverters, gates, drivers, clock generators, etc. These plug-in modules are easily replaceable and can be built into systems of any size. High reliability is achieved through the elimination of both eyelets and printed circuit connectors.

Circle 159 on Reader Service Card

Digital Voltmeter

An AC Converter has been added to a standard-model KIN TEL digital voltmeter to provide an integrated AC/DC unit. Model 402 provides 100-microvolt resolution in DC, 1-millivolt in AC. Has automatically controlled projection-type digital display, built-in printer drive. Manufactured by the KIN TEL Division of Cohu Electronics, the instrument consists of three units which can be rack-mounted separately or together: #452 AC Converter, #451 Control Unit, #471 Readout Unit.

Circle 155 on Reader Service Card

Solid Tantalum Capacitors

The addition of two new case sizes to increase the maximum capacitances available in its Type 150D series of Solid-Electrolyte Tantalex Capacitors has been announced by Sprague Electric Company. Maximum capacitances now available range up to 330μF at 6 volts, 220μF at 10 volts, 150μF at 15 volts, 100μF at 20 volts, and 47μF at 35 volts. In addition, they have added 10% EIA series nominal capacitance ratings to the listings previously available. Request Bulletin 3520C.

Circle 160 on Reader Service Card

New Literature

Four new recommended standards for the electronics industry are being made available to industry, the Electronic Industries Association announced. The standards were published following approval by representatives of the industry, including members and non-members of EIA. Representatives of EIA member-firms have received the standards which are available to all segments of the electronics industry. Non-members of EIA may obtain copies of the following standards through the EIA Engineering Department, 11 West 42nd St., New York 36, N. Y. (a minimum charge of $1 is made on all orders):

RS-186-A—Standard Test Methods for Electronic Component Parts (this standard, from Standards Proposal Nos. 562 and 577, is a revision of RS-186). $1.70.

RS-191-A—Measurement of Direct Interelectrode Capacitances (this standard, from Standards Proposal No. 579, is a revision of RS-191). $1.50.

RS-214—Method for Calculation of Current Ratings on Hookup Wire (this standard, from Standards Proposal No. 568, is new material). 60 cents.

RS-215—Basic Requirements for Broadcast Microphone Cables (this standard, from Standards Proposal Nos 574 and 585, is a revision of TR-130). 25 cents.

Circle 121 on Reader Service Card

A technical information bulletin which describes the physical characteristics, and purity standards of germanium and germanium dioxide used in the manufacture of semiconductor devices, has been made available by Sylvania Electric Products Inc. The booklet lists the minimum resistivity specifications of electronic-grade germanium measured with a 4-point probe at 25-degrees Centigrade, and, in addition, includes data on the specifications and chemical characteristics of the finished product.

Circle 118 on Reader Service Card

A complete discussion of Hall Generators, covering such points as design criteria, types currently available, applications, ratings, etc., points out the fundamental properties of these devices and their use and applications as multipliers over large dynamic ranges. This 20-page illustrated booklet includes detailed specifications on types now available, and includes all of the types manufactured by Siemens in Germany, a pioneer in this field. Available from Device Development Corp. for 25¢.

Circle 113 on Reader Service Card

A data sheet is available on the giant size Series 5000 Narda SonBlaster Ultrasonic Cleaner, manufactured by The Narda Ultrasonics Corporation. The data sheet describes Model G-5001, a 40-KC, 500-watt average output SonBlaster generator designed for energizing a wide range of cleaning tanks, and the G-5002, a 20-KC 500-watt average output generator which will operate magnetostrictive trans-

ducers for such functions as drilling, dip soldering and other high-intensity or high-temperature applications.

Circle 115 on Reader Service Card

Allied Radio Corporation announces the publication of a Semi-Conductor Directory, available free on request to all transistor and diode users. The directory covers about 1,000 transistors and diodes available from Allied's stocks and produced by 13 major manufacturers. Each transistor, diode and rectifier is listed by part number, name of manufacturer and OEM price in quantities up to 1,000 pieces. The directory is constantly being revised and is issued several times each year.

Circle 102 on Reader Service Card

Redford Corp., Instrument Division's four-page bulletin EC-201 describes uses, design characteristics, maintenance and operating features of new totalizing and predetermined counters. Semiconductor circuitry eliminates all tubes. Units are noiseless . . . count up to 500 pulses per second. Twelve standard designs available.

Circle 106 on Reader Service Card

A brochure of particular interest to the design engineer available from the Clairex Corporation, describes their series of polycrystalline photoconductive cells with illustrations and graphs of the most important characteristics of each cell. The literature lists each type of cell available, the type of material used in the cell, its size, peak response, average light resistance, and time constant; together with the cell's light to dark current ratio and temperature coefficient of resistance.

Circle 104 on Reader Service Card

Available from Solid State Electronics are data sheets describing Model 60 Solid State Electronic Chopper. This transistorized chopper is a solidly encapsulated unit designed to alternately connect and disconnect a load from a signal source. It may also be used as a demodulator to convert an a.c. signal to d.c., and is capable of linearly switching or chopping voltages over a wide dynamic range which extends down to a fraction of a millivolt. Data sheet gives complete mechanical specifications and applications.

Circle 126 on Reader Service Card

Spectrol Electronics Corporation, manufacturer of precision electronic components has released a 4-page 2-color data file 701 describing their Transidyne line of converter-inverters. The data file shows pictures of the various case styles and lists features and specifications of the four basic series.

Circle 123 on Reader Service Card

Electronic Research Associates announces the availability of a 6-page technical bulletin which provides descriptive and technical data on their new Magitran line of solid state regulated power supplies. These new designs combine the characteristics of magnetic and transistor regulators and offer novel features not previously available in conventional transistorized types. The technical bulletin includes a review of existing regulation methods, full descriptive data on the new designs and circuits.

Circle 124 on Reader Service Card

PERSONNEL NOTES

J. Gerald Mayer has been named President of Radio Receptor Co., Inc., subsidiary of General Instrument Corp., it was announced recently by General Instrument Board Chairman Martin H. Benedek. Mr. Mayer, Vice President of the parent company and a member of the General Instrument Board of Directors since June, 1956, was previously Executive Vice President of another General Instrument subsidiary, Micamold Electronics Mfg. Corp.

The appointment of Michael J. James as Sales Manager-Entertainment Products for Philco Corporation's Lansdale Tube Company Division was announced by Cyrus H. Warshaw, General Sales Manager. In his new position, Mr. James will be responsible for Lansdale sales of transistors and tubes to the radio and television industry. Mr. James has held important posts in five Philco divisions.

William L. Dudley has joined the semiconductor field engineering staff of the Sprague Electric Co., it was announced by Carroll G. Killen, manager of Sprague's corporate field engineering department at the company's headquarters in North Adams, Mass. Mr. Dudley will serve under James Balderston, who heads up the field engineering group at Sprague's Concord, N. H. semi-conductor facility. A graduate of Purdue University and M. I. T. with degrees in industrial economics and electrical engineering, Mr. Dudley was formerly an engineer with the Long Lines Department of the American Telephone and Telegraph Company.

M. H. Barnes, one of the leading specialists in the development and use of synthetic crystals, has been appointed Manager of Crystal Products for the Linde Company, a Division of the Union Carbide Corporation. His appointment was announced by Robert F. Flood, General Manager of the New Products Department of the Linde Company. Mr. Barnes has been manager of the Development Laboratory at Speedway, Indiana, since 1955. He will retain that position in addition to his new duties.

Albert W. Merck has been appointed Assistant to the Executive Vice President of Merck & Co., Inc., Henry W. Gadsden. Mr. Merck's responsibilities will be principally in the area of company marketing problems. Prior to this appointment he had been Director of Advertising and Promotion of the Merck Chemical Division since December, 1955. Mr. Merck brings to his new post a broad background of experience in the company's commercial activities since 1947.

Texas Instruments Incorporated President P. E. Haggerty announced the election of Cecil Dotson of Dallas as Chairman of the Board of Directors of Texas Instruments Limited, wholly-owned British subsidiary of the international electronic manufacturing and geophysical exploration company based at Dallas. Texas Instruments Limited has headquarters and manufacturing facilities at Bedford, England, and markets its semiconductor devices throughout the United Kingdom and Western Europe.

Industry News

Factory sales of transistors in November dropped somewhat from the all-time high sales level of October but was recorded as the second highest sales month for transistors in the history of the industry, the Electronic Industries Association announced recently. Unit sales of transistors during the first 11 months of 1958 exceeded by a considerable margin the sales of transistors during calendar year 1957. Factory sales of transistors in November totaled 5,440,981 with a dollar value of $12,441,759 compared with 5,954,856 units valued at $13,461,847 sold in October and 3,578,700 transistors valued at $6,989,000 sold in November 1957. Cumulative sales of transistors during the first 11 months of 1958, January-November, totaled 41,423,114 valued at $96,133,811 compared with 25,965,000 transistors valued at $63,120,000 sold during the corresponding 11 months period in 1957, EIA announced. Factory sales of transistors during calendar year 1957 totaled 28,738,000 units with a dollar value of $69,739,000, according to EIA's compilation. The following EIA chart shows factory sales and the dollar value of transistors in November and the first 11 months of 1958:

	1958 Sales (units)	*1958 Sales (dollars)*	*1957 Sales (units)*
January	2,955,247	$6,704,383	1,436,000
February	3,106,708	6,806,562	1,785,300
March	2,976,843	6,795,427	1,904,000
April	2,856,234	7,025,547	1,774,000
May	2,999,198	7,250,824	2,055,000
June	3,558,094	8,232,343	2,245,000
July	2,631,894	6,598,762	1,703,000
August	4,226,616	9,975,935	2,709,000
September	5,076,443	10,811,412	3,231,000
October	5,594,856	13,461,847	3,544,000
November	5,440,981	12,441,759	3,578,700
	41,423,114	$96,133,811	25,965,000

The Japanese electronic industries continued their upsurge in 1958, and for the first 9 months reported production valued at $333 million—24 percent above the comparable period in 1957—the Electronics Division, Business and Defense Services Administration, U. S. Department of Commerce reported recently. The study, compiled from reports prepared by the American Embassy in Tokyo at the request of the Electronics Division, noted also the expansion of the Japanese export market for electronic products. Production in 1957 totaled $362 million compared with $247 million in 1956, an increase of 47 percent, and in some categories—consumer electronic products and semiconductors—the total 1957 output was exceeded in the first 3 quarters of 1958. Exports of radio receivers to the United States during the period January-October 1958 totaled 1,899,574 units valued at 4.6 billion yen ($12.8 million) compared with 642,334 units valued at 1.9 billion yen ($5.3 million) for the entire year 1957. During August-October 1958, 1,019,000 units were shipped to this country. The exports consisted mainly of transistorized portable receivers. Detailed statistics from the study are available at the Electronics Division, BDSA.

:Pacific Semiconductors, Inc. announced its entry into :e commercial silicon transistor field with the dis-sure of specifications for two families of advanced :pes of Very High Frequency silicon power transistors. I. Harper Q. North, PSI president, described the new its as "triple-diffused npn junction transistors using :e mesa structure technique." "While we apply the :m 'new' to these silicon transistors, they have actually en in development for two-and-a-half years on :gnal Corps and Company-supported contracts," he id. A limited quantity of a 108mc version of the new :ple-diffused mesa transistor has already been de-:ered to the government," he said.

The formation of Continental Device Corporation as announced in Los Angeles, Calif. by Joseph S. 'Flaherty, formerly manager of the Semiconductor Div. Hughes Aircraft Co., who will serve as the new com-:any's president. Continental Device Corporation will :ecialize in the research, development, and produc-on of semiconductor devices.

Texas Instruments Incorporated has moved its Eastern egion Sales Office to Elizabeth, New Jersey, to give nproved service to customers in the growing electronics :dustry of the eastern seaboard. The region office will :oordinate the efforts of its own staff of TI sales engi-:eers and those headquartered in district offices in Cam-en, N. J., and Garden City, Long Island, N. Y. Mailing ddress of the new office is Texas Instruments Incorpo-:ated, 1141 East Jersey Street, Elizabeth, N. J.

Servo Corporation of America, manufacturer of infra-:ed and automation systems for industrial, railroad and :ilitary applications, will build a 120,000 square foot :lant in Hicksville, Long Island, N. Y. The $1.5 million :tructure will consolidate under one roof the research :nd development, manufacturing and administrative ac-:ivities of the firm's six present plants.

General Transistor Corp. has announced an agreement :o provide Van Der Heem, N. V., The Hague, Holland, :with technical assistance to manufacture a full line of NPN and PNP germanium alloyed junction and diffused :base transistors.

Increased activity in industrial instrumentation is forecast for 1959 by Henry F. Dever, vice president of Minneapolis-Honeywell Regulator Company, after what he calls a year of widely divergent trends in the applica-:tion of automatic controls. He cited a recent survey re-:porting that $70 billion would be needed to replace obsolescent equipment in the manufacturing, mining, petroleum, electric and gas, and transportation and com-:munications industries.

Millimeter Waves will be the subject of the ninth in-ternational symposium of the Polytechnic Institute of Brooklyn, Microwave Research Institute, to be held in New York City on March 31, April 1, 2, 1959, under the co-sponsorship of the Air Force Office of Scientific Re-search, U. S. Army Signal Research and Development Laboratory, Office of Naval Research, and the Institute of Radio Engineers. The symposium is intended to high-light the present state of research in, and applications of, millimeter wave technology. Accordingly, the program will be devoted to invited and contributed papers treat-ing the generation, transmission, control, measurement, and detection of millimeter wave energy. In addition, source material and significant advances in basic support-ing fields will be summarized in tutorial papers chosen from appropriate fields in physics and engineering.

[from page 51]

resistance shunt to the winding thus causing the relay to fail to operate, and a capacitor which discharges in the high-resistance direction of the rectifier thus causing the relay to operate.
2,635,223 Voltage Regulator—J. Grillo. Assignee: Ward Leonard Electric Co. An electromagnetic voltage regulating circuit utilizing bridge-connected dry-disk rectifiers to provide the field windings with a direct field energizing current.

April 21, 1953
2,636,133 Diode Gate—L. W. Hussey. Assignee: Bell Telephone Laboratories. An anti-coincidence circuit having a plurality of inputs and a common output which is adapted to produce an output signal only when a signal is applied to any one input and no other input within a defined time interval, said circuit utilizing a plurality of germanium diodes.

May 5, 1953
2,637,770 Alloys and Rectifiers Made Thereof—K. Lark-Horovitz, R. M. Whaley. Assignee: Purdue Research Foundation. A semiconducting device comprised of an alloy of germanium, said alloy consisting of 99% pure germanium in combination with nitrogen.
2,637,771 Rectifier—G. Tumulo. Assignee: Radio Receptor Co. Inc. A dry-disk rectifier in combination with a base plate having a mounting edge, semiconducting material on the surface of the plate, and a counter-electrode layer upon the semiconductor except in the region of the mounting edge.

May 19, 1953
2,639,380 Electrical Device and Method of Preparation—H. E. Hollmann. Assignee: None. An electrical device comprising a semiconductive crystal forming one electrode; a suspension of fine conductive particles in an insulating medium, said medium being bonded to the crystal; a second electrode being spaced from the crystal and in contact with the previously mentioned medium, the particles of which are oriented in the form of a fibrous chain bridging the electrodes.

May 24, 1953
2,640,164 Magnetic Ring Counter—G. J. Giel, M. C. Burns. Assignee: Berkely Scientific Corporation. A magnetic ring counter comprising a succession of reactive windings, crystal diode rectifying means having an input circuit connected in series with each of the windings and means for supplying all components from a source of alternating current.

June 2, 1953
2,640,901 Photoelectric Semiconductor Device—T. H. Kinman. Assignee: General Electric Company. The device consists of a germanium wedge, an electrode in contact with the base of the wedge, a pair of filamentary electrodes making point contact with the sides of the wedge, a light-impervious housing, and a light-bar that conducts external light to a point within the housing.
2,640,939 Phase Detector—L. Staschover, L. Rosenberg. Assignee: International Standard Electric Corporation. A phase detector for providing a voltage varying with phase angle between voltages from two a-c energy sources by utilizing two d-c voltage equivalents of the respective sources said equivalents being obtained with parallel connected resistor-rectifier networks.

June 9, 1953
2,641,638 Line-Contact Transistor—J. I. Pantchechnikoff. Assignee: Radio Corporation of America. A transistor device comprising two bodies of semiconducting material each having a discreet surface area, two filamentary conductors each in contact with one body, and means for providing intimate contact between the conductors and the bodies.
2,641,639 Point Electrode for Semiconductor Devices—B. N. Slade. Assignee: Radio Corporation of America. A device comprising a semiconductive body having a plane surface, a metallic film covering all but a predetermined area of the surface, a pair of mandrels supported above and at right angles to the surface, a pair of fine-wire compression springs each surrounding a mandrel and having a free end in contact with the surface.
2,641,712 Photoelectric Device—R. J. Kircher. Assignee: Bell Telephone Laboratories. A photoelectric device of *n-p-n* construction with terminal connections to the outer zones, and means for directing a pair of light beams against the outer zones.
2,641,713 Semiconductor Photoelectric Device—J. N. Shive. Assignee: Bell Telephone Laboratories. A photosensitive device of *n-p-n* construction with the intermediate zone being no thicker than the diffusion length of the intermediate zone minority charge carriers.
2,641,717 Transistor One-Shot Multivibrator—D. H. Toth. Assignee: United States of America (Navy Department). A device designed to provide a single-shot multivibrator of stable and long lasting characteristics and to provide also a square wave generator of extremely low energy consumption, the output thereof being initiated by a negative voltage pulse.

June 16, 1953
2,642,486 Electrical Crystal Unit—C. J. Ryan. Assignee: Sylvania Electric Products Inc. A unit comprising a tubular glass envelope, a metal sleeve sealed at one end thereof, a semiconductive crystal attached to said sleeve, a beaded metal sleeve to seal the other end of the tube, and a catwhisker contact to the crystal.

July 7, 1953
2,644,852 Germanium Photocell—W. C. Dunlap, Jr. Assignee: General Electric Company. A photosensitive device comprising a germanium wafer with a maximum thickness of 0.050 inches, said wafer consisting of a *p*-type region, an *n*-type region, and a *p-n* junction.
2,644,859 Stabilized Semiconductor Amplifier Circuits—L. E. Barton. Assignee: Radio Corporation of America. A transistor amplifier circuit is provided in which the negative resistance which appears looking into the base electrode is substantially balanced or counteracted by a positive resistance without decreasing the gain of the circuit.
2,644,892 Transistor Pulse Memory Circuits—J. B. Gehman. Assignee: Radio Corporation of America. This circuit provides a memory unit which will develop an output pulse of predetermined fixed amplitude in response to an interrogating pulse when an input pulse has previously been applied within a predetermined interval of time.
2,644,893 Semiconductor Pulse Memory Circuits—J. B. Gehman. Assignee: Radio Corporation of America. A transistor circuit comprising a means for impressing input pulses between the emitter and the base, said pulses momentarily biasing these electrodes in the forward direction; means for impressing reverse-biasing interrogating pulses between the collector and the base; and a load impedance across which an output pulse is developed.
2,644,894 Monostable Transistor Circuits—A. W. Lo. Assignee: Radio Corporation of America. A device designed to provide a regenerative transistor amplifier or monostable triggered circuit having a high gain and developing an output pulse of a shape which is substantially independent of the amplitude and wave shape of the input or trigger pulse.
2,644,895 Monostable Transistor Trigger Circuits—A. W. Lo. Assignee: Radio Corporation of America. A device designed to provide a monostable triggered circuit which will develop an output pulse of predetermined amplitude and width in response to a trigger pulse, and where the leading edge of the ouptut pulse may be delayed with respect to that of the trigger pulse.
2,644,896 Transistor Bistable Circuit—A. W. Lo. Assignee: Radio Corporation of America. A circuit having a stable state of low current conduction, another stable state of high current conduction, and a non-linear resistance device having a high resistance when the circuit is in the low current conduction state and a low resistance when the circuit is in the high current conduction state.
2,644,897 Transistor Ring Counter—A. W. Lo. Assignee: Radio Corporation of America. A ring counter having several counter stages connected in a closed loop, each of said counter stages comprising a bistable transistor circuit having a low and high stable state of current conduction.
2,644,914 Multicontact Semiconductor Translating Device—R. J. Kircher. Assignee: Bell Telephone Laboratories. A device comprising a wafer of semiconductive material, an ohmic connection to said wafer, and point contact connections to the wafer.
2,644,915 Selenium Rectifier and Method of Its Production—E. A. Thurber, L. A. Wooten. Assignee: Bell Telephone Laboratories. A rectifier comprising an iron base-plate, a uniformly thin matrix coating of finely divided nickel particles, a selenium coating overlying the nickel coating, and a counter-electrode on the selenium layer.

July 21, 1953
2,646,536 Rectifier—S. Benzer, K. Lark-Horovitz. Assignee: Purdue Research Foundation. A point contact semiconducting rectifier assembly.

July 28, 1953
2,646,609 Crystal Amplifier—H. Heins. Assignee: Sylvania Electric Products Inc. The method of forming a multielectrode semiconductor unit including the steps of applying a metallic layer to the semiconductive body and applying the point contact.
2,647,162 Electroacoustical Signal Transducer—R. K. Duncan. Assignee: Radio Corporation of America. A vibration-sensitive device is coupled to the collector and emitter electrodes in such a way that the motion of the vibrating device causes the electrodes to tilt and roll their tips over the semiconducitve body with which they are in contact; thereby varying the interelectrode distance.

Book Reviews . . .

TITLE: Junction Transistor Electronics

AUTHOR: Richard B. Hurley

PUBLISHER: John Wiley & Sons, Inc. 1958

Junction Transistor Electronics is a well coordinated book presenting a most understandable and useful description of the transistor in terms of a physical concept of operation.

The book deals succinctly and thoroughly with transistor physics in Chapter I. This is followed by a low level diode and triode analysis culminating in a functional equivalent circuit of the triode transistor. The "h" parameter and "T" parameter equivalent circuits are identified in terms of the parameters of the transistor. The physical concept of transistor operation is developed throughout the analysis.

Chapter III is a complete collection of the formulae for the gain and impedance for each of the various configurations. The exact equations are listed, together with a tabulation of a first approximation and a limited aproximation. A table of reverse connection formulae *i.e.*, reversed output and input terminals, and tables of power gain, special terminations and approximate gains round out the listed data.

Chapter IV develops the audio frequency amplifier in terms of small signal operation. The tables of the previous chapter are used in illustrative examples with a comparison of the errors present in the various approximations. Methods of bias stabilization and noise in transistors are topics treated in the following two chapters.

The remainder of the book discusses the usual variety of topics: power amplifiers, *d-c* amplifiers and regulators, high-frequency circuits, oscillators, switches and frequency selective amplifiers. Also included are chapters on feedback, modulation, and saturable-reactor circuits.

Junction Transistor Electronics is a book that is unusual in the *clarity* of presentation of the material. Mr. Hurley has succeeded in writing a true textbook on transistors that will undoubtedly find its place as a basic reference on transistor electronics.

TITLE: The Junction Transistor and its Applications

EDITOR: E. Wolfendale

PUBLISHER: The MacMillan Company 1958

This book has been written by a staff of engineers and physicists of the Mullard Corporation of Britain. Much of the approach to the topic is slightly different from that usually found in American text books; however this is an advantage in understanding the material.

The first three chapters deal with the physical characteristics of the transistor. Transistor physics are clearly discussed in terms of the fundamentals of semiconductors. The *p-n* junction is described with a rigorous mathematical treatment of the current-voltage equation. The transistor is presented in terms of two *p-n* junctions and the equivalent circuits are derived. Because of the complexity of the material the authors advise the inexperienced engineer to return to the first chapter after he develops a better understanding of transistors in general. This should not detract from the value of the material covered in later chapters, which is quite understandable.

The next chapters are concerned with circuit applications. Methods of *d-c* bias and uses of the transistor as an audio amplifier are described in Chapter IV. High frequency and class C amplification are discussed in Chapters V and VI. Oscillators and a very interesting analysis of *d-c* power converter operation may be found in the remaining chapters of the book together with a useful review of transistor measurements.

The Junction Transistor and its Applications is a very extensive compilation of design theory, approach and techniques. The value of this work lies in the very complete illustrative examples of the design of circuitry utilizing principles carefully developed throughout the book.

TITLE: Control Engineers Handbook

AUTHOR: Staff of specialists
edited by John G. Truxal

PUBLISHER: McGraw Hill 1958

Control Engineers Handbook is a collection of the works of thirty six authors, each contributing to the fund of information presented. The book deals specifically with feedback control systems and their various components.

The second section of the work defines the feedback system and the factors of stability and relative stability. Here may be found the basic definition and theory of control engineering. The book itself is a logical expansion of the theory into techniques and components used in control systems.

Section 3 sets forth the design methods in terms of problem statement, component analysis and systems analysis. The next section deals with specialized design techniques by means of network synthesis and matrix manipulations. A particularly interesting review of computers in control may be found in Section 5.

The balance of the book is devoted chiefly to components. There are sections on transistor circuit design and miniaturization (Section 8), thyratron amplifiers (Section 9), servo mechanisms and mechanical components. The physical aspects of gearing and control are well treated.

Control Engineers Handbook is a definitive compilation of data, techniques and systems which should provide a basic reference work for the engineer interested in controls. The treatment of material is far more thorough than is usually found in "handbooks" and the book is exceptionally well written and indexed.

Stephen E. Lipsky

Index to Advertisers

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Write for complete engineering data sheet to the Technical Literature Section, Sprague Electric Company, 467 Marshall Street, North Adams, Massachusetts.

* *Sprague micro-alloy, micro-alloy diffused-base, and surface barrier transistors are fully licensed under Philco patents. All Sprague and Philco transistors having the same type numbers are manufactured to the same specifications and are fully interchangeable.*

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